APPENDIX D:

TECHNICAL FEASIBILITY ANALYSIS

MOBILE APPLICATION FOR GEOLOCATION OF IMAGERY AND COLLABORATION

MAGIC

Prepared By:
MAGIC Team
Jeff Carpenter
Thomas Haas
Dawin Wright
Erika Rojas Mejia

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Course Professor: Dr. Kathryn Laskey
Project Sponsor: Kurt Rogers, Integrity Applications Inc.

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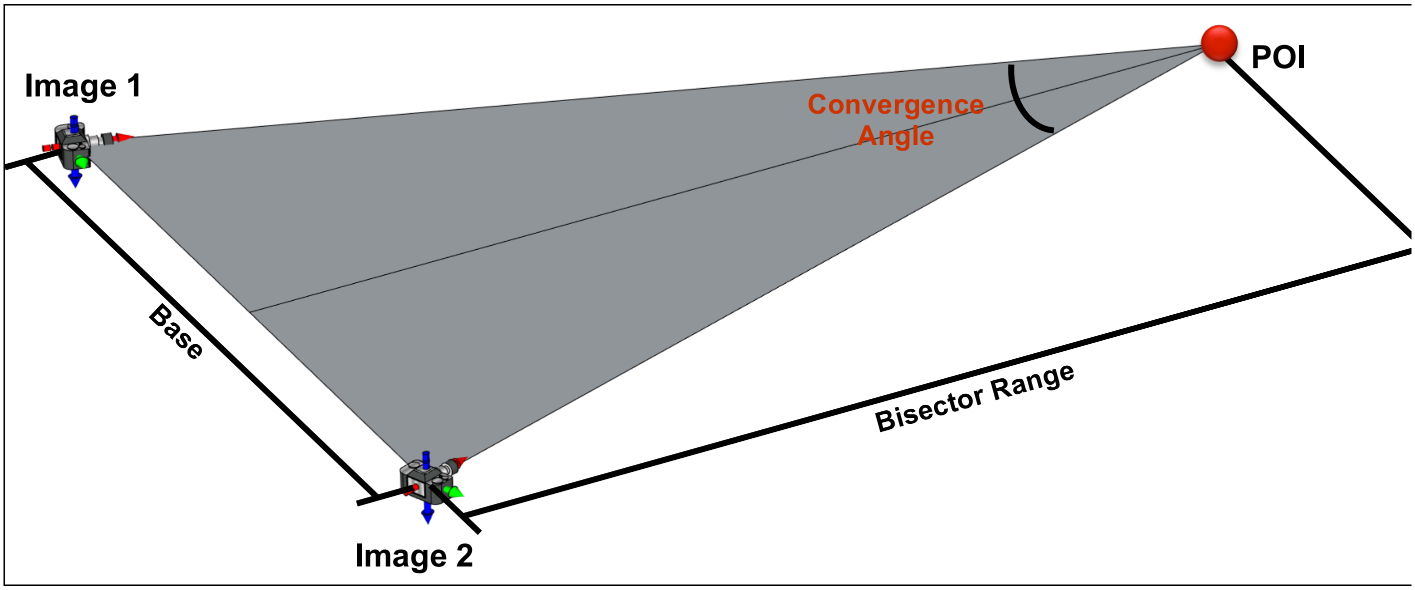
Intro

The Mobile Application for Geolocation of Imagery and Collaboration (MAGIC) will generate and share geolocated Points of Interest (POI) and the images used to create them. While it is theoretically possible to achieve this capability based on the sensor sweet available in today's smartphones, there is no information on how accurate the calculation based on smartphone data is or what potential users needs would be. The purpose of this technical feasibility analysis is to identify & compare the needs of the MAGIC users identified in the MAGIC CONOPs to the currently available technology to determine if the proposed application will be able to meet their needs, and if so what current platforms and systems might provide the best user experiences. This analysis will look at three primary areas of concern:

1. The first is the geolocation requirements and performance, the analysis will look into how well the users will need to know the location of points of interest (POI) and with how much certainty they will need to know those locations and how they will share image and POI data.
2. The second portion of the analysis will look at several smartphones currently in the market place to identify their capabilities and examine if they will be able to meet the user's needs.
3. The last portion of the analysis will look at possible methods to enable image and POI sharing for the users. It will identify current social networking services and determine if their interfaces are sufficient to support these services, or if additional data services will be needed to support the sharing portion of the MAGIC application.

User Geolocation Requirements

The MAGIC Concept of Operations identified two primary user groups, the Emergency responder and the casual or social user. These two user groups are evaluated to identify how they are expected to use the application, what their expectation for performance will be and use those to establish accuracy and confidence requirements.



How the users employs the application will define the geometry of the image used in the calculation which results will be dependent upon. The standoff distance from each image location to the POI and the distance between the image locations will define a triangle with specific bisector range and base as shown in Figure 1. These geometric properties will be used to define the bounds of the accuracy requirements.

First Responder/Emergency Responder

This user group's use of MAGIC will be performed under critical conditions with lives potentially depending on the user's ability to identify and communicate POIs with a fair degree of accuracy and a moderately high degree of confidence in accuracy. Two of the most common uses for the application were identified and used to determine objective requirements.

The first potential emergency use of MAGIC considered was the geolocation of victims in open water. The US Coast Guard performs open sea rescues and in 1955 Field Study of Detectability of colored targets at sea shows that typical marine emergency equipment and objects are detectable with low probability at over a mile in good viewing conditions. (1) To achieve 90% or greater detectability the observer had to be within approximately 0.4 miles of their object or less. Based on this study emergency MAGIC users would need to achieve accuracies of approximately 600 meters with 90% confidence from up to 1.6 kilometers away. The open sea scenario presents major difficulties for MAGIC. There are virtually no photo identifiable[1] objects at sea other than the victims and the victims themselves would likely be at different geolocations in the images used to calculate their location to do currents and wave motion resulting in inaccuracte geolocation calculations and large error estimates. Additionally the existence of International Rescue beacon systems like COSPAS and SARSAT however reduce the

[1] A photo identifiable object is an object within an image that can be distinctly identified in multiple images.

likelyhood an emergency user would need to use MAGIC for open sea geolocation. So the open sea rescue case will not be considered for the development of MAGIC.

Littoral and inland rescues occur most regularly during disaster relief efforts and present a much more likely and supportable role for MAGIC. The U.S. Coast Guard rescued or evacuated over 33,500 people after Hurricane Katrina in 2005. (2) “Search and rescue operations alone saved 24,135 lives from imminent danger, usually off the roofs of the victims’ homes…” (3) Unfortunately the Earthquake and tsunami that struck Japan in March of 2011 is another example where addresses and pre-disaster maps of little use to helicopter pilots as entire cities and landforms were wiped from the landscape. The location of victims would not need to be overly precise but would need to be small enough that the emergency crews could be sure the victims were within an easily search able area. Based on the rescues that occurred after hurricane Katrina in New Orleans the need accuracy would be approximately the size of the average suburban home near New Orleans. A simple survey of the size and spacing of the houses in these areas most affected by flooding after Katrina would require a 90% confidence in the horizontal and vertical error and an accuracy of 50m for bisector and base distances less than 600m.

Social Networker/Tourist

The second user group identified will not generally use MAGIC under emergency conditions, which reduces the need for a high degree of confidence in the accuracy of the calculated location. However, these users will likely be unsatisfied, and not use or recommend MAGIC, if the accuracy of the POIs is continually poor. For this reason the accuracy requirements for the casual user will be higher but the confidence can be lower.

A general survey of public images shared on some of the most popular social networking and photo sharing websites show two primary categories of images likely to be used for identifying and sharing POIs by MAGIC users. The first is portrait or scenic portrait photos. These images have individuals as the primary subject, who are likely to be identified as the user’s main POI to be geolocated. The subjects are usually within a few feet and up to approximately one hundred feet away from the camera. The scenic portraits may also contain landmarks or other potential POIs to be located in the background. These objects may be at the same distance as the primary subject or at much greater distances than the primary subject. The second category of images is landscape photography. The primary objects in these images are generally stationary landmarks at distances from the user between approximately 500 feet to 2 or 3 miles at the very extreme.

These users do not have the same critical need for high confidence in the error estimate as the emergency users, but the desired accuracies are an order of magnitude higher than the emergency user, in other words, the Social user will likely be more sensitive to inaccuracies in the calculated location of the POIs even if they are not as worried about the size of the confidence area around the POI. Large and regular inaccuracies in the calculated POI locations will lead the user to be dissatisfied with MAGIC and stop using the application as well and not recommending it to new users. For this reason the objective accuracy requirement for the social user will be 10 meters with a 50% confidence in the horizontal and vertical error for bisector and base distances less than 300m.

Table 1: User Geolocation Requirements

	Threshold Requirements	Objective Requirements
Accuracy (m)	50	10
Confidence (%)	90	50
Bisector / Base Distance (m)	600	300

Table 1 presents the geolocation accuracy requirements for MAGIC based on the analysis of the two primary users groups identified in the MAGIC Concept of Operations. The requirements for the emergency user are less strict for accuracy of the calculate POI and will be used as the threshold requirement. In order to proceed with the development of MAGIC it should be shown that current smartphones will be able to meet these requirements. The casual user requirements will be used as objective requirements. It is expected MAGIC will be more appealing to the target users if it can achieve these accuracies.

Current Smartphone systems and Capabilities

Today's smartphones are highly sophisticated sensing and computing devices. The basic mathematic calculation necessary for performing multi-image geolocation could easily have been handled by processors generations ago. The real advances in smartphone technology that will enable the capability to perform these calculations are the imaging and other sensor now being used in smartphones. Cameras can capture high resolution images, other sensors capture position and orientation measurements, memory to store the data, powerful processors quickly perform the computations and high bandwidth radios communicate large amounts of data rapidly. For this analysis it will be assumed that any smartphone capable of downloading and using MAGIC will have sufficient a sufficient camera, memory, processor power and communication capabilities to meet both user groups needs. The addition of Global Positioning System capabilities, Digital Magnetic Compass (DMC), 3-axis Accelerometer and in some cases 3-axis gyroscopes are the major technological additions to smartphones in the past several that will enable MAGIC's geopositioning capability by providing data about the position and orientation of the smartphone as the images are taken and these sensor accuracies will determine the accuracy of MAGIC's geolocation results.

MAGIC will need to support the collection of this metadata from each smartphone and package it with each image taken. The accuracy of this metadata is the primary factor in the accuracy of the geolocation result for MAGIC. Frame Sensor Model Metadata Profile Supporting Precise Geopositioning Version 1 by the National Geospatial-Intelligence Agency's Community Sensor Model Working Group (CSMWG) describes the primary metadata items required for the generic sensor model. Of the elements described in the paper the primary elements that will contribute to errors in MAGIC are sensor position, and sensor orientation. (3) The smartphone sensors that measure and report these values are the Global Positioning System (GPS), the DMC, and 3 axis accelerometer. The GPS provides the X, Y and Z position of the camera on the Earth when the image is taken, but it does not provide information about where the camera is pointed. The DMC provides pointing information about the absolute azimuth angle of the camera relative to the magnetic north pole at the time the image is taken. The 3 axis accelerometer provides pointing information about the absolute elevation angle relative to the gravity vector and the roll angle of the camera at the time the image is taken. Recently more smartphones are being equipped with gyroscopes to measure the direction and rate of rotation about all three axes. While a gyroscope doesn't provide any measures of absolute position or orientation its data can be combined with that of the DMC and accelerometers to obtain a better estimate of the cameras orientation when the image is taken, it may also be useful in maintaining system calibration. Each of these sensors have errors in their measurements that must be accounted for and modeled in the sensor model or estimated and accounted for in the 'catch-all' error parameter Unmodeled System Error. These errors account for the uncertainties about the measured smartphone position and pointing. Other system errors are internal system errors caused by lens distortions and other offsets and misalignments. The last major component to total system error is the timing architecture. The timing architecture controls when the different sensor measurements are recorded, large or unknown timing differences between sensors may result in metadata that does not correspond closely to the image which they are indented to support. Error estimate or confidence in the location of the calculated POI can also be improved (or degraded) based on real-time feedback from the sensors on their accuracy. For example GPS systems often use Dilution of Precision calculations to modify the predicted accuracy of the users coordinates in real-time. (4) These errors about the sensors measured values should be know as well as the values themselves.

Required Sensors:

Camera: Records the image of the object(s) to be geolocated.
GPS: Records the absolute position of the smartphone for each image taken by the camera.
Digital Compass: Measures the absolute azimuth angle of the smartphone for each image taken.
3-axis Accelerometer: Measures the absolute elevation and roll angle of smartphone for each

Optional Sensors:

3-axis gyroscope: Measures relative direction and rate of rotation

Before proceeding with development of MAGIC it is necessary to determine if smartphones available today are capable of meeting the accuracy requirements of the identified user groups. To do this three of the most recent and popular smartphones were identified and researched to determine what sensors they have and to get an estimate on the accuracy of their sensors. Additionally the operating system for each phone is assessed to determine what if any timing architecture is implemented and how accessible the sensor data is for capture as image metadata and error estimates. The three smartphones are the Apple iPhone4 running iOS4, the Samsung Galaxy S running Android 2.2 and the HTC Evo 4G running Android 2.2.

Apple iPhone 4 and iOS 4

Figure 1: iPhone 4 with iOS4

Sensor components specs

Camera
The iPhone4's primary camera is a 5 mega pixel (MP) (2592x1944) color CMOS QSXGA array. (6) (7)

GPS
The GPS is the Broadcom BCM4750 single chip GPS receiver. (6)

Compass
The magnetometer is the AKM Semiconductor AKM8975. (6)

Accelerometers
The accelerometer is the STMicro LIS331DH 3-axis accelerometer. (6)

Gyroscope
The gyroscope is the STMicro L3G4200D 3-axis gyroscope. (6)

Timing architecture
iOS4 provides access to the GPS system, accelerometer, gyroscope, and imagery time stamp for the time at which the location, elevation angle, roll angle, and image were captured. (8) Currently no documentation specifying the relationship between the different time stamps has been indentified (i.e. is there lag between the actual device position/angle/shutter release and the captured value or the time placed in the time stamp element?)

Access to 'raw' sensor data and sensor error Information

Core Motion's sensor fusion algorithms in iOS process both accelerometer and gyroscope data and provide an application with highly accurate measurements of device attitude, the (unbiased) rotation rate of a device, the direction of gravity on a device, and the acceleration that the user is giving to a device. (8) The raw accelerometer and gyroscope data is available for independently developed fusion algorithms. iOS also provides access to the GPS system estimate of horizontal and vertical accuracy's. (8) The specifications for the sensors in the iPhone4 do not indicate the ability to provide real-time estimates of the other sensors confidence in the measured values. Appropriate error values will need to be determined from sensor specifications and system testing or accounted for in unmodeled error.

Estimated System Accuracy

Initial non-rigorous tests indicate that the iPhone4 is capable of a very accurate GPS position under normal conditions, on the order of 1 to 5 meters. The orientation is less well known. The absolute azimuth has been estimated to have an error of approximately +/- 10 degrees and an error of approximately +/- 5 degrees in pitch and roll. Calibration of the sensors and use of the gyroscopes should be able to reduce the system errors and improve relative accuracy between temporally close imagery.

Samsung Galaxy S and Android 2.2

Figure 2: Samsung Galaxy S with Android 2.2

Sensor components specs

Camera

The primary camera is an unidentified 5 MP CMOS sensor.

GPS

ST Ericsson GNS7560 Single Chip GPS Solution. (9)

Compass

5 MP rear facing CMOS. (9)

Accelerometers

The 3-axis accelerometer is manufactured by Bosch Sensortec but a specific model could not be identified. (9)

Gyroscope

The gyroscope is the STMicro L3G4200D 3-axis gyroscope. (9)

Timing architecture

Android Sensor Event Class captures a time stamp for each sensor and the sensor state including sensor's type, the time-stamp. (10) Android also provides access to the time the image was taken. (10) Currently no documentation specifying the relationship between the different time stamps has been indentified (i.e. is there lag between the actual device position/angle/shutter release and the captured value or the time placed in the time stamp element?)

Access to 'raw' sensor data and sensor error Information

In addition to the time stamp data the SensorEvent Class also provides accuracy and the measured sensor data. (10) The SensorManager Class provides direct access to the raw sensor data as well although the implementation is not as straight forward as the iOS implementation as Android's architecture must support different hardware providers.

Estimated System Accuracy

The similarity of the Galaxy S's hardware with that of the iPhone and non-rigorous testing indicates that the GPS position accuracies under normal conditions are on the order of 1 to 5 meters. The accuracy of the orientation data is less well known. The absolute azimuth has been estimated to have an error of approximately +/- 10 degrees and an error of approximately +/- 5 degrees in pitch and roll. Calibration of the sensors and use of the gyroscopes should be able to reduce the system errors and improve relative accuracy between temporally close imagery.

HTC Evo 4G and Android 2.2

Figure 3: HTC Evo 4G with Android 2.2

Sensor components specs

Camera

OmniVision OV8812 8 Mp Image Sensor with a 1.4 µm pixel. (11)

GPS

Qualcomm's RTR6500 CDMA2000 transceiver with GPS. (11)

Compass

The magnetometer is the AKM Semiconductor AKM8975. (12)

Accelerometers

Bosch Sensortec BMA150 Digital, triaxial acceleration sensor. (11)

Gyroscope

Not Applicable

Timing architecture

Android Sensor Event Class captures a time stamp for each sensor and the sensor state including sensor's type, the time-stamp. (10) Android also provides access to the time the image was taken. (10) Currently no documentation specifying the relationship between the different time stamps has been indentified (i.e.

is there lag between the actual device position/angle/shutter release and the captured value or the time placed in the time stamp element?)

Access to 'raw' sensor data and sensor error Information

In addition to the time stamp data the SensorEvent Class also provides accuracy and the measured sensor data. (10) The SensorManager Class provides direct access to the raw sensor data as well although the implementation is not as straight forward as the iOS implementation as Android's architecture must support different hardware providers.

Estimated System Accuracy

The similarity of the Evo's hardware with that of the Galaxy S and the iPhone indicate that the GPS position accuracies under normal conditions are on the order of 1 to 5 meters. The accuracy of the orientation data is less well known. The absolute azimuth has been estimated to have an error of approximately +/- 10 degrees and an error of approximately +/- 5 degrees in pitch and roll. Calibration of the sensors should be able to reduce the system errors and improve relative accuracy between temporally close imagery, however because the Evo lacks a gyroscope it likely will lose calibration much faster and require re-calibration more often to maintain the best geolocation results.

Data and Metadata

All of the cameras in these smartphones are framing cameras. A framing camera is an imaging sensor which collects the full image (data from every pixel) at the same time. This type of sensor is usually a focal plane array (FPA) made of a charged coupled device (CCD) or Complementary metal–oxide–semiconductor (CMOS). CMOS sensors are the sensor type generally used in smartphone cameras, due to their compact size and image quality. A sensor model describes the mathematical relationship between the how objects appear in the image and the actual position of the objects on the Earth. (13) A sensor specific model can be developed for individual sensors and would require specific sensor specifications to be coded directly into the models. These models are limited because they can only be used with image from the specific sensor they were written to work with and their development is usually time and resource intensive. With the potential number of different smartphones MAGIC would be used on this would be a cumbersome and expensive way to develop models for these sensors. A generic sensor model is a non specific framing sensor model. It defines the equations and variables to be used in the geolocaiton calculations but relies on metadata from each image about the camera that took the image to populate those equations. A generic frame sensor model will be used to mitigate the issue of managing many different sensor models. The generic model will require specific information about each image and the smartphone used to take the image in order to be able to accurately calculate the location of POIs within the images. This information is referred to as image metadata or image support data. "Frame Sensor Model Metadata Profile Supporting Precise Geopositioning" by the National Geospatial-Inteligence Agency provides an overview of a detailed set of metadata to support geolocation using a frame sensor model. MAGIC will use a subset of this metadata set for calculation of POI geolocation. Table 2 below lists the metadata parameters MAGIC will need to capture and embed in each image.

Table 2: Metadata Elements (4)

Metadata Element	Definition	Comments
Sensor ID	A unique ID for each smartphone	Unique ID would be used to apply any camera specific corrections applied from a look up table developed in later camera calibration efforts.
Number of Columns of pixels in the image	C, the number of columns in the sensor array. (unitless)	

Number of Rows of pixels in the image	R, the number of rows in the sensor array. (unitless)	
Sensor Collection Time	Time each image and metadata parameter is collected.	It is recommended to use Portable Operating System Interface (POSIX) where time is in integer microseconds since 1 Jan 1970. Applies an IEEE standard which provides required significant number precision. Algorithms exist to incorporate required leap seconds to convert to UTC.
X_L – Sensor Perspective Center Position at Sensor Collection Time (t)	X, location of the sensor in the geocentric coordinate system at time of exposure	Primary exterior orientation position parameter required for sensor location.
Y_L- Sensor Perspective Center Position at Sensor Collection Time (t)	Y location of the sensor in the geocentric coordinate system at time of exposure	Primary exterior orientation position parameter required for sensor location.
Z_L – Sensor Perspective Center Position at Sensor Collection Time (t)	Z location of the sensor in the geocentric coordinate system at time of exposure	Primary exterior orientation position parameter required for sensor location.
Roll: Sensor Rotation about the translated platform X_p -axis	The rotation of the sensor in the yz-plane of the sensor reference frame; measured as positive when positive y-axis rotates directly towards the positive z-axis.	
Pitch: Sensor Rotation about the translated Platform Y_p-axis	Rotation around the once rotated sensor y'-axis" defined as the rotation of the sensor in the once rotated x'z'-plane of the sensor reference frame; measured as positive when the positive z'-axis rotates directly towards the positive x'-axis.	
Yaw: Sensor Rotation about translated Platform Zp-axis	Rotation around the sensor twice rotated z"-axis defined as the rotation of the sensor in the x"y"-plane of the sensor reference frame; measured as positive when the positive x"-axis rotates directly towards the positive y"-axis.	
Sensor Focal Length	f, lens focal length; Effective distance from optical lens to sensor element(s). A community accepted value of 999.99 indicates focal length is not available or not applicable to	

	this sensor.	
Sensor position and attitude accuracy variance data	$\sigma^2_{X_L}, \sigma^2_{Y_L}, \sigma^2_{Z_L}$ $\sigma^2_{\omega}, \sigma^2_{\phi}, \sigma^2_{\kappa}$ Variance (sigma^2) data for position (X_L,Y_L,Z_L), and attitude angles (ω, ϕ, κ)	Usually estimated on the basis of original data or from photogrammetric processing such as triangulation. Conditional if standard deviations are provided instead.
Sensor position and attitude accuracy covariance data	$\sigma_{X_L Y_L}$, $\sigma_{X_L Z_L}$, $\sigma_{Y_L Z_L}$, $\sigma_{X_L \omega}$, $\sigma_{X_L \varphi}$, $\sigma_{X_L \kappa}$, $\sigma_{Y_L \omega}$, $\sigma_{Y_L \varphi}$, $\sigma_{Y_L \kappa}$, $\sigma_{Z_L \omega}$, $\sigma_{Z_L \varphi}$, $\sigma_{Z_L \kappa}$, $\sigma_{\omega \varphi}$, $\sigma_{\omega \kappa}$, $\sigma_{\varphi \kappa}$	If any are known

In the initial iteration of MAGIC several internal system parameters identified in the NGA document (not listed in Table 2 above) will be considered as unmodeled error because they require much more detailed hardware insight and or camera calibration than could be supported. These include Principle point offset which describes the offset from the optics center axis and the center of the focal plane, decentering distortion which describes tangential distortions in the optics, radial distortion which describes pin cushion and barrel distortion effect, atmospheric refraction which occur as light propagate through the air and, sensor offsets/lever arms which describe the position and orientation of the sensors within the smartphone relative to each other. (4) In the event that MAGIC generates a sufficient income stream there is the potential to perform camera calibrations of the most popular hardware platforms and provide lookup tables for static parameters values in later updates of MAGIC which would result in even more accurate results for those smartphones.

This metadata item identified in Table 2 must be stored with each corresponding image in order to allow users to perform geolocations using shared images. This presents a problem because smartphones generally save images in the Joint Photographic Expert Group (JPEG) format which doesn't support the storage of all the necessary metadata. In order to manage the image metadata for each image and enable sharing of the image and metadata in an uncomplicated manor MAGIC will need to save the images taken in the Tagged Image File Format (TIFF). Several metadata elements including sensor location, location accuracy, image size, focal length and camera ID can be stored in standard EXIF or XMP metadata tags used in both JPEG and TIFF image. Other metadata elements including sensor orientation are not supported by JPEG and will require that MAGIC develop a Private Tag header extension for TIFF to point to an Image File Directory in the TIFF header which will store the additional metadata in Extensible Markup Language (XML) or a to be define binary format. The exact implementation will need to be determined during development of the application but should keep in mind the three potential sources of metadata (lookup table, EXIF/XMP tags and Private Tags).

The geolocation calculations will result in Point of Interest files. These files will contain POI name, description, location, horizontal and vertical errors and potentially links to the images from which they were generated. These POI files will be separate Google KML files for easy interaction and sharing on Google Maps and Google Earth. The KML can be extended to include any additional tags not native in kml.[19] (5) Required tags for POIs files will include KML tags <name>, <description> and <coordinates>. Necessary extensions to KML will include tag and attributes <associatedImage filename= pixel=>.

Example Calculation

This section will outline the mathematic principles used for the multi-image geolocation algorithm used in MAGIC to calculate POI locations. The derivation of the location of the point of interest from two images is based on a photogrammetric multi-image point extraction using the collinearity equations. This case assumes ideal conditions with the object to be located at the image center. For each image the vector from the sensor perspective center (L) to the image point (a) and the vector from the perspective center to the object point (A) are collinear for the ideal case. (3)

$$\begin{bmatrix} u \\ v \\ w \end{bmatrix} = M^T \begin{bmatrix} X - X_L \\ Y - Y_L \\ Z - Z_L \end{bmatrix} \qquad \text{Eq. 1}$$

Where M is the rotation matrix which accounts for the transformation from the sensor coordinate system to the Earth coordinate system and u, v and w are the image space coordinates (pixel row, pixel column and minus the focal length) for each image. (3) The equation for the line through the perspective center of the image and the object point is

$$\frac{X-X_L}{u} = \frac{Y-Y_L}{v} = \frac{Z-Z_L}{w} \qquad \text{Eq. 2}$$

When combined with a second image the result is a system of four equations and three unknowns

$$u_1(Z - Z_1) - w_1(X - X_1) = F_1$$

$$v_1(Z - Z_1) - w_1(Y - Y_1) = F_2$$

$$u_2(Z - Z_2) - w_2(X - X_2) = F_3$$

$$v_2(Z - Z_2) - w_2(Y - Y_2) = F_4 \qquad \text{Eq. 3}$$

where [F_1, F_2, F_3, F_4] is a misclosure vector, which can be solved using a least square estimation with the errors in the smartphone position and attitude measurements captured in the covariance matrix Q. (6)

$$Q = \begin{bmatrix} {\sigma_X}^2 & 0 & & \cdots & & 0 \\ 0 & {\sigma_Y}^2 & & & & \\ & & {\sigma_Z}^2 & \ddots & & \vdots \\ \vdots & & \ddots & {\sigma_{Az}}^2 & & \\ & & & & {\sigma_P}^2 & 0 \\ 0 & & \cdots & & 0 & {\sigma_R}^2 \end{bmatrix} \qquad \text{Eq. 4}$$

Based on this method an estimate of the geolocation performance of the smartphones can be calculated. The results of these initial estimates can be refined with a more complex model as more parameters are taken into account. Best and worst case examples are presented herein and additional results exploring sensitivity to GPS and point error are provided in Appendix E. The error graphs are contour plots where the contours show the estimate horizontal and vertical errors for the defined cases. The X and Y axes are the base and bisector distance, respectively, of two images used to calculate a POI, as depicted in Figure 1.

For the worst case the position errors are set to four meters for X, Y and Z with attitude errors of 10 degrees in azimuth and 5 in pitch and roll and assessed at the 90% confidence level.

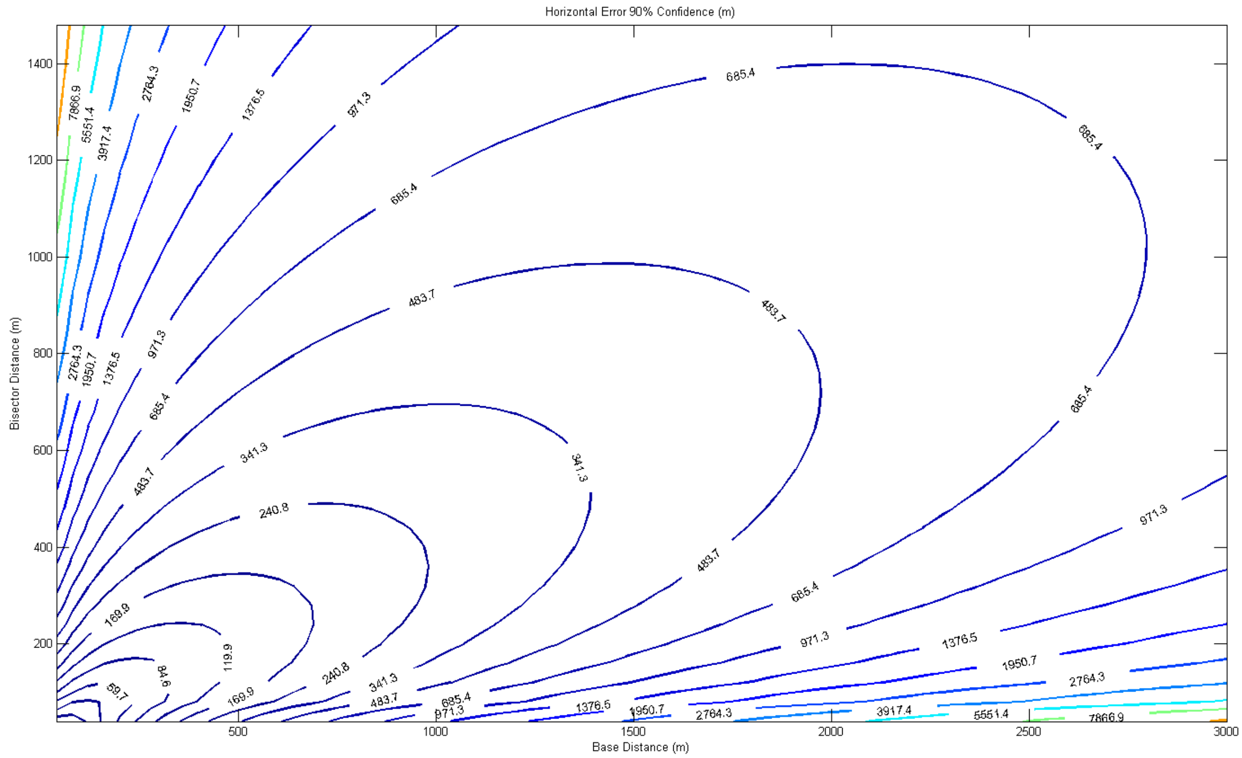


Figure 4: Horizontal Error at 90% confidence for estimated worst case position and pointing errors

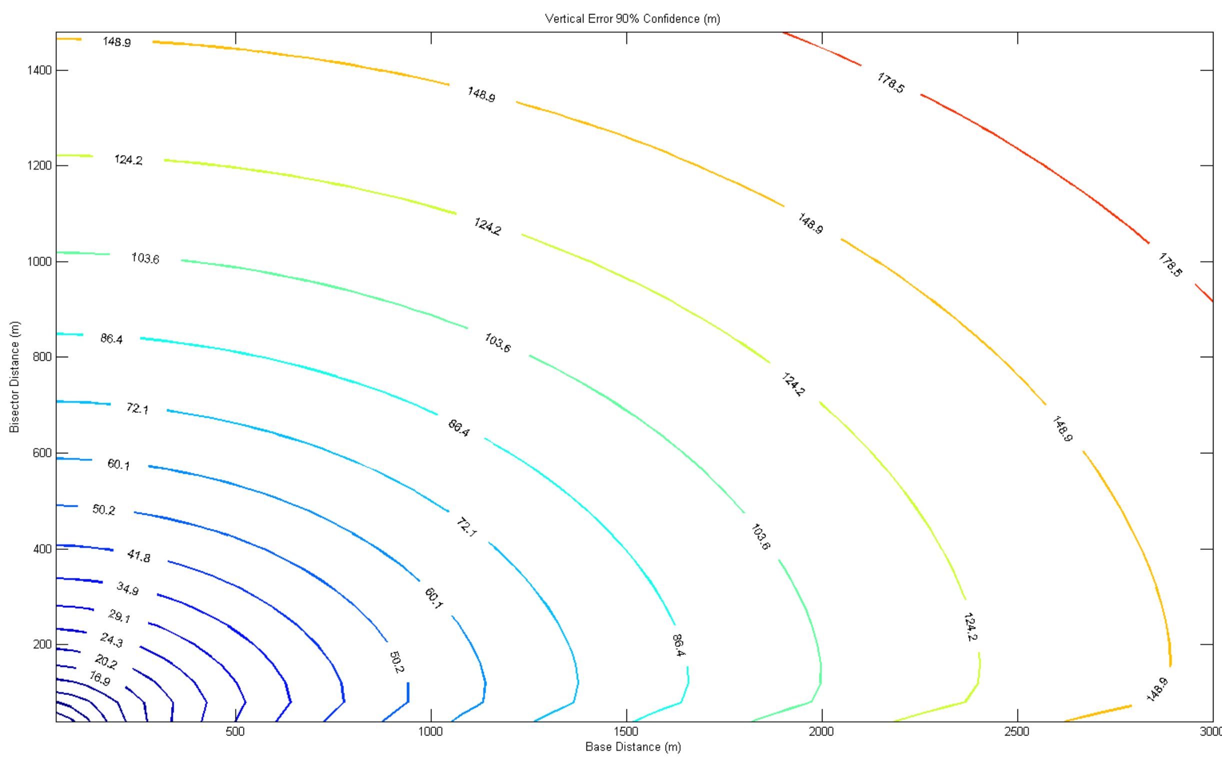


Figure 5: Vertical Error at 90% confidence for estimated worst case position and pointing errors

Figure 4 and Figure 5 show that error estimates for the worst case scenario. The horizontal error is under the desired 50m for 90% confidence close to the origin of the graph representing image combination with small base and bisector distances, but does not meet the desired accuracy at the base and bisector distance in the threshold requirement. The vertical error meet the threshold performance for some parts of the operational envelope as the large uncertainties in the azithum angel don't play as large a role as they do in the calculation of horizontal error.

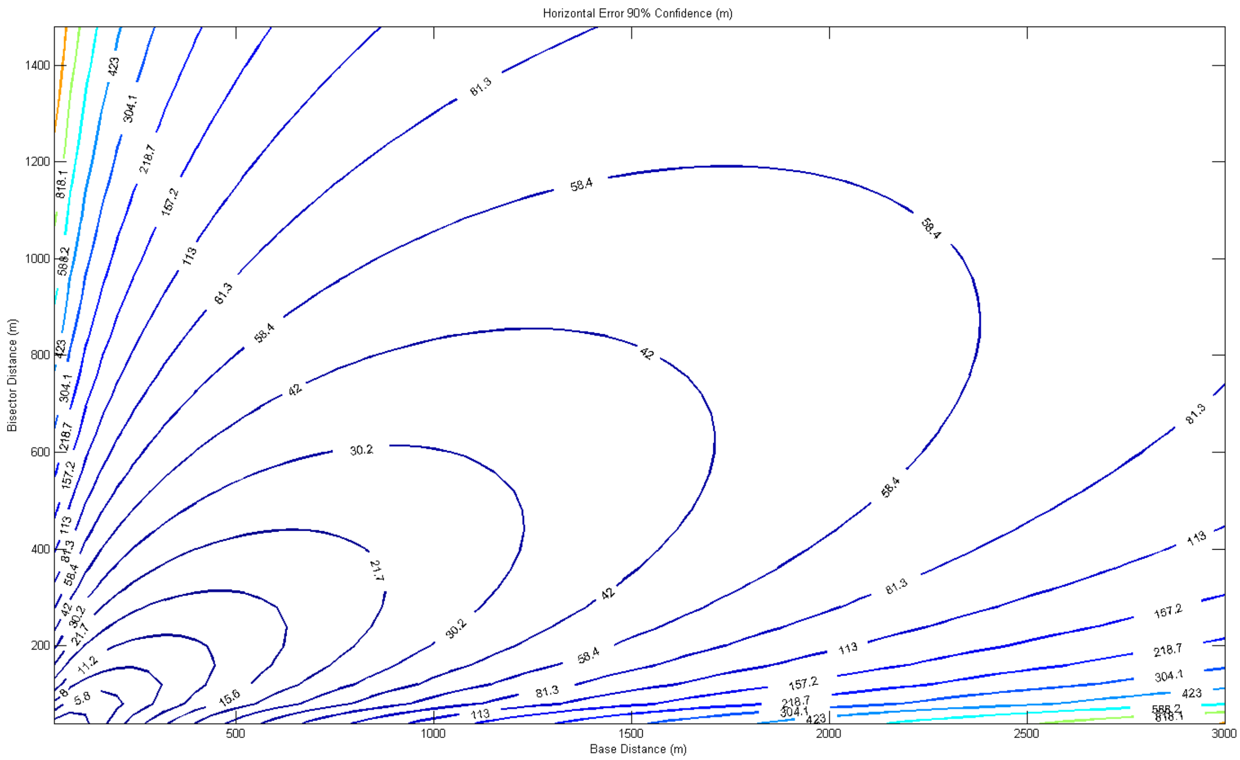


Figure 6: Horizontal Error at 90% confidence for estimated best case position and pointing errors

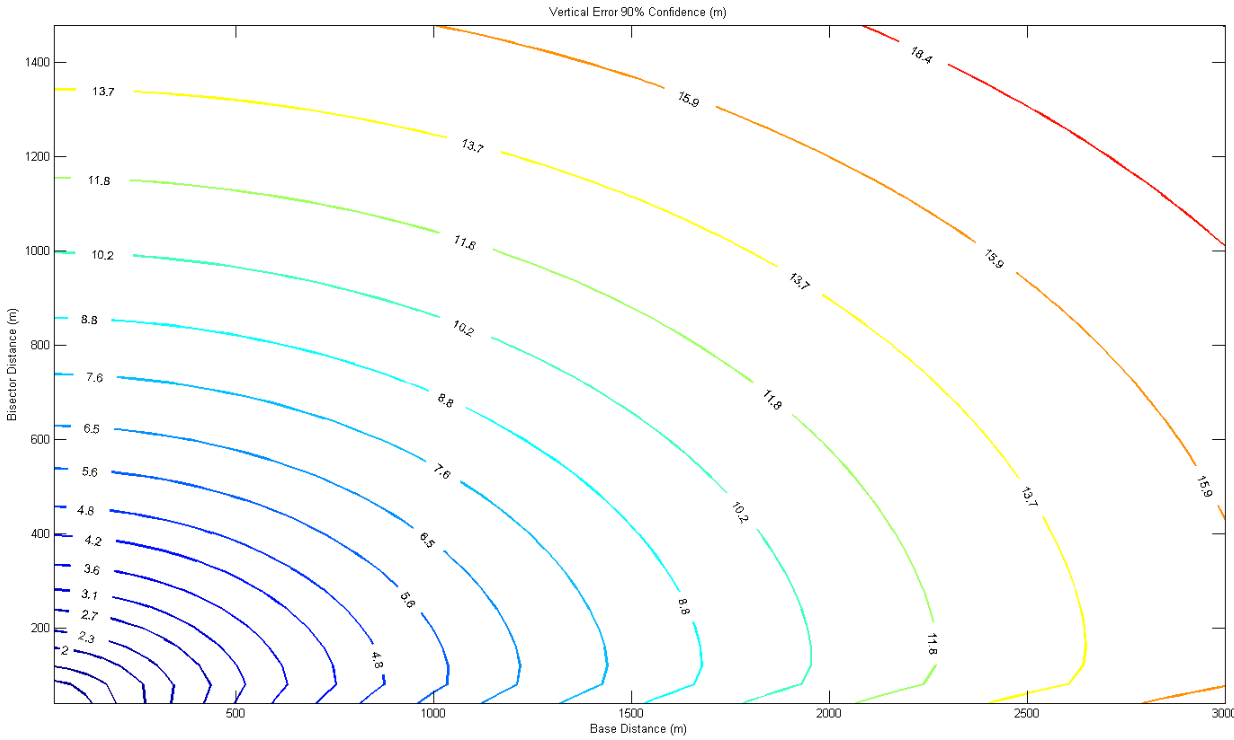


Figure 7: Vertical Error at 90% confidence for estimated worst case position and pointing errors

Figure 5 and Figure 7 show that the threshold requirements are acheivable at and beyond the desired base and bisector distances. The best horizontal error performace occurs where base distance is twice the bisector distance which represents image pairs which are othoganal to each other. The vertical error meet the thershold requirement for all of the operational envelop shown in the graph.

The Objective Requirements and a sensitivity analysis are presented in Appendix E. The Object Requirements are achievable for calibrated smartphones and the sensitivity analysis verifies that the geopositioning error estimates are more sensitive to errors in pointing than position for most of the operational envelop with the exception being for very small base and bisector distances. Smartphones without Gyroscopes may not be able to achieve this level of accuracy for long after calibration where smartphones with gyroscopes may be able to hold their calibration longer and require calibration less often to achieve this level of accuracy. The degradation of the calibration over time for both types of smartphones should be studied.

User Data & Sharing/Collaboration Requirements

While MAGIC will enable individual users to collect multiple images and perform the geolocation of POIs natively on their smartphones even without network connectivity, the social networking and sharing is a large part of smartphone use. Pew Internet research found in 2010 that 54% of mobile phone users have sent a photo or video to someone, 23% have accessed social networks and 15% have posted photo online. In September of 2010 Nielsens reported more than 10% of mobile internet use was spent on social networking.

This section will analyze the needs of the two primary user groups identified and assess them against existing social networks. If these existing networks are not sufficient to meet these needs, this analysis will look at into the possibility of developing a standalone MAGIC Server; however, a detailed analysis of such a server is outside of the scope of this effort.

Social Networking/Tourist

Social users will share images and POIs over the Internet for the purpose of having others view the photos and associated POIs within the image, view photos and POIs on the map UI and use images to generate new POIs for themselves. In order to perform these tasks with shared photos and POIs the services providing access must be compatible with tiff image and KML files and must not strip any metadata from the images. The privacy needs of the users must also be satisfied for users who share images, however any images shared for MAGIC must contain external camera metadata parameters and possibly some internal metadata parameters. User should be able to select at a minimum whether to share specific images with everyone (publicly available) or a select group of approved contacts.

First Responder/Emergency Responder

The emergency users will also need to share image and POIs files for viewing and use in other geolocation calculations. The emergency users will share all images and POIs they generate, but don't ever need to share files with the public. This will require some firewalls between their data and the public internet and a large amount of storage. Additionally the CONOPs proposed for the emergency user describes a central command web interface to perform geolocation task using shared data from users in the field.

Current Sharing/Collaboration Services

This section takes a look at four of the most popular social networking and image sharing websites to assess if they might be a solution for the sharing and collaboration portion of MAGIC. Lastly the possibility of a standalone MAGIC server is addressed.

Twitter

Twitter is a social networking and microblogging website, which enables users to send and read text-based posts composed of up to 140 characters, called tweets, which are displayed on the user's profile page. Users can subscribe to other users' tweets. By default, tweets are publicly visible, though senders can restrict message delivery to just their followers. Users can tweet via the Twitter website, compatible external applications (such as for smartphones), or by Short Message Service (SMS) available in certain countries. (7) Users cannot send images or other data via 'tweets' and it is therefore not a useable platform for sharing image and POI data. However, MAGIC should consider interfacing to Twitter as a means for users to alert their Twitter followers to new MAGIC images and POIs they have created in order to create awareness of MAGIC and spread its user base. Users could connect to their account and each time they share a photo or POI on the selected service a link to that image or POI could be provided to those people following the user on twitter, this would also expose more people to MAGIC and potential increase the total number of users.

Facebook

Facebook is a social networking website where users may create a personal profile, add other users as friends, and exchange messages, including automatic notifications when they update their profile, change their status and upload pictures. Additionally, users may join common interest user groups, organized by workplace, school or college, or other characteristics. Facebook allows users to upload an unlimited number of photos. (8) Facebook however deletes image metadata due to privacy issues and would thereby render MAGIC images shared over Facebook unusable for geolocation. Again due to the large user base on Facebook, MAGIC should consider interfacing with Facebook. Users could connect to their account and each time they share a photo or POI on the selected service and a link to that image or POI could be posted to their Facebook Wall, this again would also expose more people to MAGIC and potential increase the total number of users.

Flickr

Flickr is an image hosting and video hosting website, web services suite, and online community. (9) Flickr's self stated primary goal is to 'get photos and video into and out of the system in as many ways as we can: from the web, from mobile devices, from the users' home computers and from whatever software they are using to manage their content. And we want to be able to push them out in as many ways as possible: on the Flickr website, in RSS feeds, by email, by posting to outside blogs or ways we haven't thought of yet.' (10) Flickr saves TIFF metadata which would enable users who share image via Flickr to use them for additional geolocations. Flickr however limits uploads per month for users who don't purchase a Pro account, image access must be managed from 'within' flickr account. Flickr does not allow users to share non-image files and therefore the POI files would require some other sharing service which would then need to include a capability to associate the images on Flickr with the POIs. This presents additional complications but is potentially possible. Further analysis of this interaction is outside the scope of this effort but it should be evaluated in follow-on efforts.

Google Picasa Web Albums

Picasa Web Albums (PWA) is a photo sharing web site from Google, often compared to Flickr and similar sites. (11) PWA limits storage to a total of 1 GB for user although additional space can be purchased. Like Flickr, PWA saves TIFF metadata, image access must be managed from within PWA (or Google Picasa Photo software) and users are only able to share image files and not other data types. Solutions similar to those proposed for Flickr may be possible and integration with Google maps and Google Earth for sharing POIs and view both image and POIs is an interesting possibility. PWA and Flickr represent possible solutions for image and POIs sharing although the interaction would likely be complicated and difficult to manage. Further analysis of this interaction is outside the scope of this effort but it should be evaluated in follow-on efforts.

MAGIC Standalone Server

A standalone MAGIC server would provide the most flexibility and customization although the increased expense and developing and implementing a customized server should be researched. A standalone server is also likely the only way to meet the needs of the emergency users and its development can be leveraged regardless of which user group is targeted first. If the application is initially developed for the emergency users some of the cost in developing and standing up the services can be covered by the contract with the organization acquiring the application. The services will them be able to be leveraged as the application is moved to the public sector for the social user. If the markets are approached in the other order the cost of the server development will not be immediately covered; however having the capability already developed and proven may make the system more marketable to the organization acquiring the application for the emergency users. The specifics on the detailed design of the server is out of the scope of this current effort.

Summary

The purpose of this analysis was look at three primary areas of concern:

> The first is the geolocation requirements and performance, the analysis will look into how well the users will need to know the location of points of interest (POI) and with how much certainty they will need to know those locations and how they will share image and POI data.
>
> The second portion of the analysis will look at several smartphones currently on the market to determine if these user requirements will be achievable.
>
> The last portion of the analysis will look at possible methods to enable image and POI sharing for the users. It will identify current social networking services and determine if their interfaces are sufficient to support these services, or if additional data services will be needed to support the sharing portion of the MAGIC application.

The users identified in the MAGIC Concept of Operations are the Emergency User and the Social Networking/Causal User. The needs of the Emergency User were used to establish a minimum threshold requirement for geolocation accuracy of 50m with a 90% for images with a base or bisector distance of 600 meters. The Social networking user provided an objective requirement of 10m with a 50% confidence for a base of bisector distance of 300 meters.

Three of the most recent and popular smartphones and their operating systems were analyzed to establish their sensor suites and provide an estimate of their sensor errors. The three phones were the iPhone4, Samsung Galaxy S and HTC Evo 4G. While the sensors and operating system varied the performance of the system were very similar. The assessment in the study showed that the threshold requirements are achievable for calibrated smartphones and the follow on analysis and sensitivity study show that the objective requirements may also be achievable.

MAGIC will need to save the images as TIFF files with specifically designed Private tag headers and the POIs will be stored as KML files. The possibility of sharing of these files was assessed for several of the most popular social networking and image sharing websites. Twitter and Facebook are not compatible with sharing the necessary image or POI data but should be included in MAGIC as a means to allow users to alert their followers and friends of new MAGIC images and POIs and a method to increase awareness of MAGIC potentially increasing MAGIC's user base. It may be possible to share the image and POI data using a combination of Flickr, Google Picasa Web Albums and Google Earth, but it is the recommendation of this study that a standalone server be researched in a follow on study. A dedicated MAGIC server would likely allow for a simple and manageable sharing and collaboration service not achievable by trying to leverage existing websites.

The study shows that MAGIC is technically feasible for the most recent smartphones running both Apple iOS and Google Android and that it is prudent to continue begin market research and system design.

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