3D Flood Simulation System using RS & GIS

Sangyal Lama Tamang[1]
[1]Student (M.Tech), Computer Science &Engineering, Sikkim Manipal Institute of Technology, Sikkim, India

Victor Saikhom[2]
(Dr) Ng Romeji Singh[3,]
[2] Scientist/Engr SD, North Eastern Space Application Center, Meghalaya, India

Zigmi T Bhutia
[4] Student (M.Tech), Information Technology, Sikkim Manipal Institute of Technology, Sikkim, India

***Abstract*— Flood damage assessment and risk analysis are important issues in disaster management and mitigation. The planners cannot deal with emergency management and disaster relief because of the lack of timely (real time) flood inundation information. Meanwhile, the public also cannot quickly identify at-risk area and realize the potential threat. Therefore, it is very significant to develop an information system to predict, prepare and estimate the flood inundation to mitigate the flood disasters. This paper introduces a relative method to predict the area vulnerable to flood and to apply the results to prepare for protecting infrastructure and people within the related inundated area. The simulated results can be used to delineate the potential flood hazardous areas in large regions and then the damage from disasters can be reduced. This study focuses the way to predict the area vulnerable to flood by a 3-D numerical model calibrated with past records of inundation and geographic information available. The geographical information is used to build up the three-dimensional numerical grid and to support decision making for minimizing flood related damages based on the simulated results**

Keywords*— *Flood, Shallow Water Equation, Flood Disasters, Flood Plain Delineation, MIKE FLOOD

I. INTRODUCTION

With the onset of climatic changes implying an amplified or increased frequency of floods in many regions of the world [1] and a steadily increasing number of economic assets being located within flood-prone areas, the need to understand and protect our society against flooding has become increasingly important. The spatial characterization of hazard and risk is of utmost importance in any flood-management plan. Hence, an appropriate, rapid, and effective response to any flood-induced disaster area is essential. Therefore, only remote sensing with its extensive spatial coverage with respect to the field measurements collected at high temporal resolution is capable of delivering the needed kind and quantity of information to meet these objectives satisfactorily.

At present, flood modelling and simulation play a very important role and help to make a real contribution to the work against flood hazards. Some efficient flood modelling and post-flood damage estimation systems have been designed for solving or mitigating the loss [2][3]. But as seen the systems developed have lacked the support of GIS data and it would be difficult to apply it into the flood inundation mapping. At the same time, it was developed for 2D environment and was not integrated with a large-scale 3D environment.

Hence due to the intuitive result, large-scale 3D environmental modelling is becoming more and more popular. Over the past few years, it has become increasingly common to use image-based reconstruction techniques on realistic terrain models [4] [5] [6]. So finding a process to present terrain in real-time and reconstruction techniques for modeling the real world remains a challenge for a feasible solution. Therefore in order to overcome these problems, a new urban flood risk-analysis prototype system has been proposed which includes digital terrain modeling and a flood spreading model

A. Objectives

To achieve the expected goal the following objectives need to be satisfied:

a) To integrate the needed spatial information and the related database.
b) To establish 3D models of terrain to simulate a flood event.
c) To develop a 3D Flood simulation format.
d) To display 3D Flood simulation, the distribution of flood inundation and estimate the flood damage.

B. Digital Terrain Map (DTM)

Digital Terrain Map (DTM) uses GIS theory as the basis. It digitizes the elevation data to display the undulate terrain. The data formats for GIS presentation are composed of Raster Data and Vector Data in general. There are three types of presentation for digital elevation model (DEM): Triangulated irregular network (TIN), Digital contour and Regular grid [7].

C. Flood Risk Management System

After the successful generation of 3D digital real environment, the next step is to focus on integrating the constructed river terrain with flood simulation model for flood risk management. The proposed flood risk management system is outlined in Fig. 2.

II. STUDY AREA

The study area is located in Shillong the state capital of Meghalaya in the North-eastern part of India Meghalaya, with the total area of about 22,429 Km2, is situated in Shillong Plateau at an altitude of more than 1000 m. Monsoon impacts this region directly making Meghalaya the wettest place in India (Average annual rainfall: 1,200 cm) and rich in water power resources. The study area is located along Wah Umkrah River with the coordinates 25° 34´51N to 91°53´59E. The Shillong city is situated along the northern slopes and foothills of the Shillong peak at 25°34´N latitude and 91°53´E longitude at an average altitude of 1496 metres above mean sea level [8]. Wah Umkhrah rivers flowing through Shillong urban originate from the foothills of in the eastern hill peak of the city. Wah Umkhrah River flows in the West direction and falls in the Umiam lake.

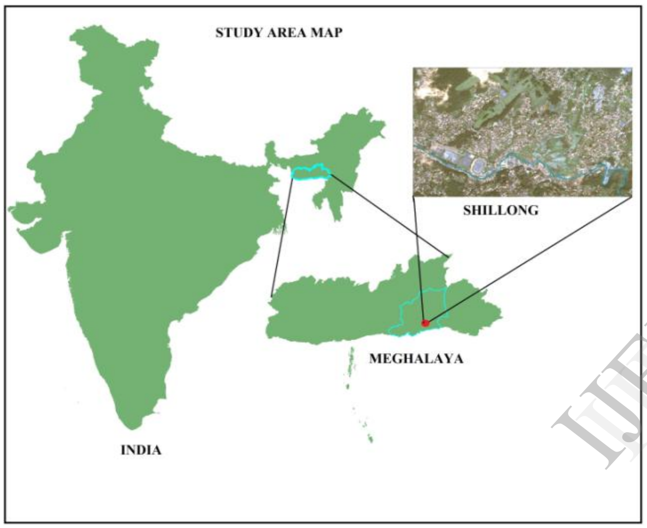

Fig. 1: Location map of study area

III. DATABASE USED

This study uses DEM and hydro metrological data to simulate the flood-impacted area and building. To execute and estimate the extent of floodplain mapping through floodplain simulation the integration of hydraulic model with GIS was carried out.

A. Spatial Data

IRS P5 CARTOSAT-1 Stereo (acq: 2008 to 2010) with 10,000 scale having a resolution of 2.5m are used for the extraction of the DEM and the GeoEye-1 image (acq: 2010) with a resolution of 0.5m is used as the multispectral image. Additional DGPS and GPS points were also adopted.

B. Hydro Metrological Data

For the hydrological data we used the rainfall data collected from the Automated Weather Station (AWS) located at 92.14E, 25.23N. Mainly the discharge data and the water level data were used for the boundary conditions in the MIKE 21 simulation. The rainfall data were cross checked with the Tropical Rainfall Measuring Mission (TRMM) grid data which is a satellite designed to monitor and study tropical rainfall.

C. Ancillary Data & Ground Survey Points

Along with the spatial data and the hydrological data the GPS points were also gathered by visiting the study area as the ground truth points from the field.

IV. METHODOLOGY

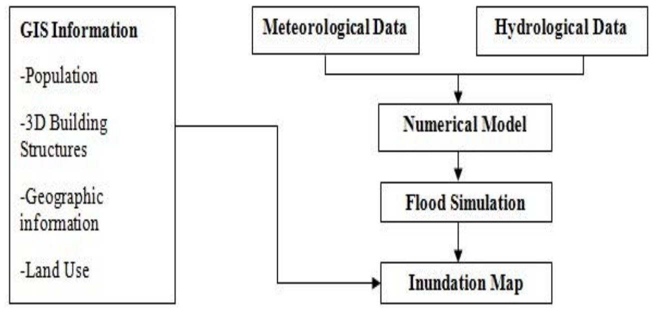

Fig. 2: Conceptual Diagram of 3D Flood Simulation System

A. Hydraulic Model

a) 1-D model: Traditionally, the one dimensional models have been extensively used as inundation models, despite being mainly designed to simulate flow inside natural or artificial channels. Mike-11 is a widely used one-dimensional flow routing modelling, developed in 1987 by the Danish Hydraulic Institute, which has been used widely to simulate water levels and flow in river systems [9-10]. The core to this model is a hydrodynamic module, which solves the Saint-Venant equations (non-linear equations of open channel flow), and the kinematic wave or diffuse wave simplifications to simulate the flows within branched and looped river networks [11]. The hydraulic model requires as input the output hydrographs from The MIKE 11 model; the boundary flow time series, cross-sections with contraction and expansion coefficients, roughness coefficients represents a surface resistance to flow and are integral parameters for calculating water depth. These can be defined either globally or locally for each cross-section. The quality of the results is dependent upon the distance between the cross-sections.

b) 2-D model: In literature, the definition "2D models" is generally used to identify hydraulic modes based on the 2D depth-averaged governing equations of flow, usually called Shallow Water Equations (SWE). 2D models can be further classified in dynamic, gravity, diffusion or kinematic wave models, according to the formulation adopted for the SWE; in addition, models based on the fully dynamic SWE can include shock-capturing schemes and different turbulence closure methods. Dynamic wave models retain all the terms of the momentum equation, whereas gravity wave models neglect the effects of bed slope and viscous energy loss and describe flows dominated by inertia. When the acceleration terms in the SWE are neglected, the diffusive wave model, or zero inertia model is obtained. Finally, the further omission of the water depth gradient terms brings to the kinematic wave equation. 2D flood inundation models are generally based either on the diffusive or fully dynamic SWE [12]. We used the MIKE 21 model to construct the 2D components.

c) 1D-2D coupled model: Significantly a large number of flood inundation models adopt an integration of both the 1D-2D approach, in order to exploit the advantages of both the modeling schemes. Hence in these models the 1D model is used to represent the flow in the river reaches, coupled with a 2D scheme that activates when flow out of river bank occurs. In this study we have used the MIKE FLOOD model to dynamically integrate the 1D river model and 2D overland flow model.

B. *Numerical Formulation*

MIKE 21 HD is a simulation tool, which simulates water wave dynamics in lakes, bays, coastal areas and seas by solving a set of hyperbolic partial differential equations called shallow water equations which model the propagation in incompressible fluids, under the condition that the vertical length scale is small compared to the horizontal length scale. The solution scheme is the Alternating Direction Implicit (ADI) method, which results in a lot of tri-diagonal matrix systems, which have to be solved efficiently [13]. The shallow water equations are a set of hyperbolic partial differential equations. The equations are constructed from the theory of conservation of mass and momentum, and the partial differential equations that describe the flow and water level variations are as follows

$$\frac{\partial \zeta}{\partial t} + \frac{\partial p}{\partial x} + \frac{\partial q}{\partial y} = \frac{\partial d}{\partial t} \qquad (1)$$

$$\frac{\partial p}{\partial t} + \frac{\partial (\frac{pp}{h})}{\partial x} + \frac{\partial (\frac{pq}{h})}{\partial y} + gh\frac{\partial \zeta}{\partial x} + \frac{gp\sqrt{p^2+q^2}}{C^2h^2} - \frac{1}{\rho\omega}\left(\frac{\partial (h\gamma_{xx})}{\partial x} + \frac{\partial (h\gamma_{xy})}{\partial y}\right) - \Omega_q - fVV_x + \frac{h}{\rho\omega}\frac{\partial (pa)}{\partial x} = 0 \qquad (2)$$

$$\frac{\partial q}{\partial t} + \frac{\partial (\frac{q^2}{h})}{\partial y} + \frac{\partial (\frac{pq}{h})}{\partial x} + gh\frac{\partial \zeta}{\partial y} + \frac{gq\sqrt{p^2+q^2}}{C^2h^2} - \frac{1}{\rho_w}\left(\frac{\partial (h\gamma_{yy})}{\partial y} + \frac{\partial (h\gamma_{xy})}{\partial x}\right) - \Omega_p - fVV_y + \frac{h}{\rho_w}\frac{\partial (pa)}{\partial y} = 0 \qquad (3)$$

Where the time, t, in seconds and the two space coordinates, x and y, in meters are independent variables, Ω *(x, y)* is the Coriolis parameter(latitude dependent s^{-1}), *C(x, y)* is the Chezy resistance(m1/2/s) ,*d(x, y, t)* is the time varying water depth(m), *h(x, y, t)* is the water depth, γ as components of effective shear stress in *xx, xy, yy* direction, ρ_w is the density of water, $V, V_x, V_y(x, y, t)$ is the wind speed and components in x and y direction. The dependent variables are the surface elevation, ζ , in meters and the two-dimensional flux densities, p and q in m3/s/m.

V. DATA PROCESSING AND FLOOD SIMULATION

A. *Terrain Processing For Floodplain Delineation*

LPS 2013 was used to develop the digital elevation model (DEM) for the study area. The block adjustment project in LPS environment with ten Cartsoat-1 stereo pairs was created for the study area using 25 GCPs collected from the DGPS survey with Root Mean Square Error (RMSE) of 0.31. The integrated MIKE 11 GIS provided extensive tools for thorough channel and surface geometry modeling that included floodplain processing. Using the DEM module requires that data be processed in MIKE21 FLOOD established steps, where contour data is converted from shape theme to .xyz file and corrected area definitions assigned before DEM is generated. Additional Arc GIS themes were used to further improve the terrain data by going for hydrological correction of the DEM.

B. *MIKE 21 Bathymetric Processing*

Hydrological correction of CARTOSAT 10m DEM was carried out using the filling procedure in ArcGIS and then converting it into an ascii format to move it into the MIKE21 interface. Minor noises left after the hydrological correction were removed using various filtering procedures. The river bed was depressed using the data from field survey for the clear visibility of the river bathymetry, since the river profile in the bathymetry was not clear. All the erroneous areas near the upstream and downstream points near the river were corrected using the interpolation method in the MIKE 21 environment. A constant high elevation value of 1475 m which are always dry with no possibility of flooding was considered for closing the four sides of the model taken from the contour elevation values.

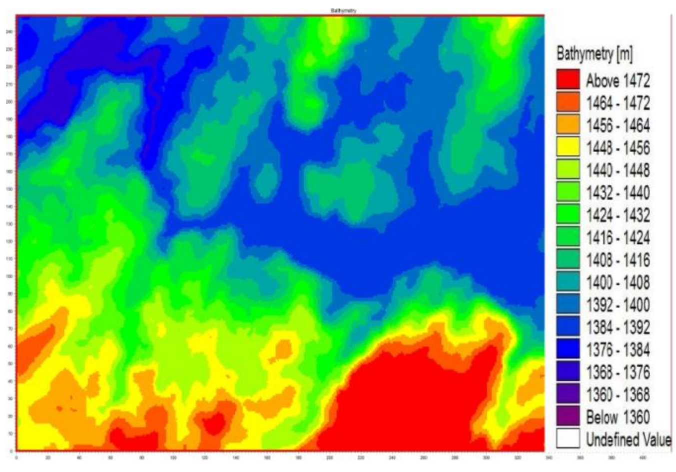

Fig. 3: DEM of study area

C. *Flood Inundation 2D Simulation*

a) Boundary Conditions: For initial boundary conditions we considered the upstream as variable inflow with input as discharge hydrograph and the downstream input as stage hydrograph. The initial conditions in river such as water depth and discharge were taken as 0.4 and 20 respectively. 1

second for 3 days was considered as the time step for the simulation.

In flood related studies, not only the extent of flooded areas but also the depth of water in the flood affected area should be determined to help predict the damage that water will cause to both land property. To determinate the inundated area in the flood map the subtraction of flood surface elevation model from the land surface elevation model at each location need to be carried out, resulting in negative values wherever the flood elevation is greater than the land elevation.

VI.RESULTS AND DISCUSSION

The presented models are evaluated at a test scenario in Shillong, a flooding which occurred in June 2011at the Wah Umkrah River. Various results were generated for a course of three days when the flooding occurred and were analyzed when the maximum inundation had occurred. The results consist of inundation map which were generated only due to the increased discharge in the river and also with rainfall that occurred and how it contributed to the flood inundation map. The hydrological data feed consists of the hydro graph which is generated on the three hourly rainfall data provided by the Automated Weather Station (AWS) located at Shillong.

The model stable state reached at approximately 12 hours from the time of start. We found that the rainfall factor was visible around 11:40 am of the first day. Due to the absence of significant infiltration and storage in urban area, rainfall was applied both at wet and dry computational cells.

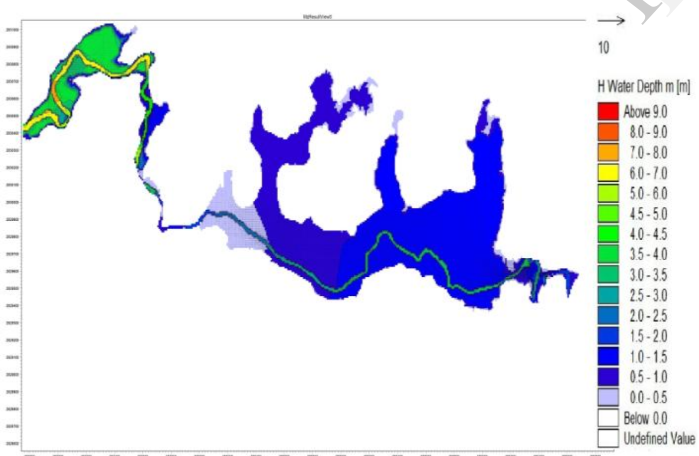

Fig. 4: Inundation map without rainfall

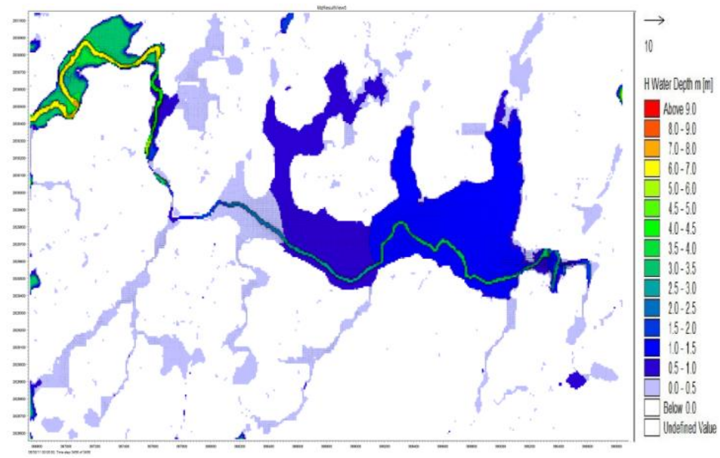

Fig. 5: Inundation map with rainfall

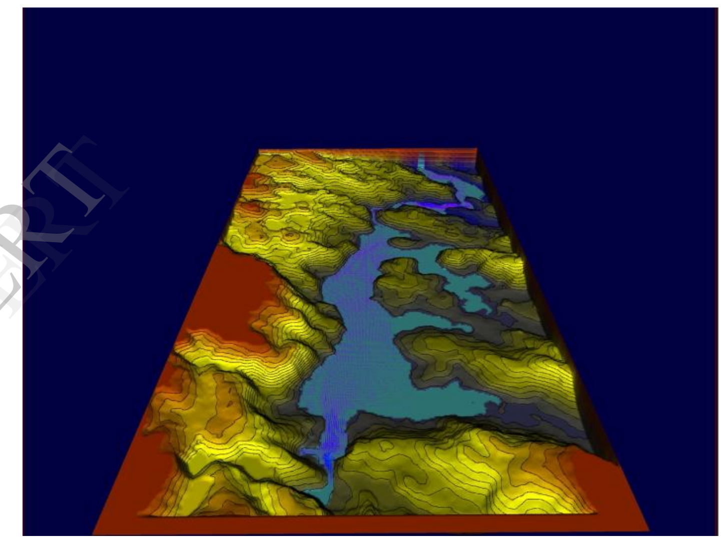

Fig. 6: Inundation map without rainfall in MIKE Animator for 3D visualization

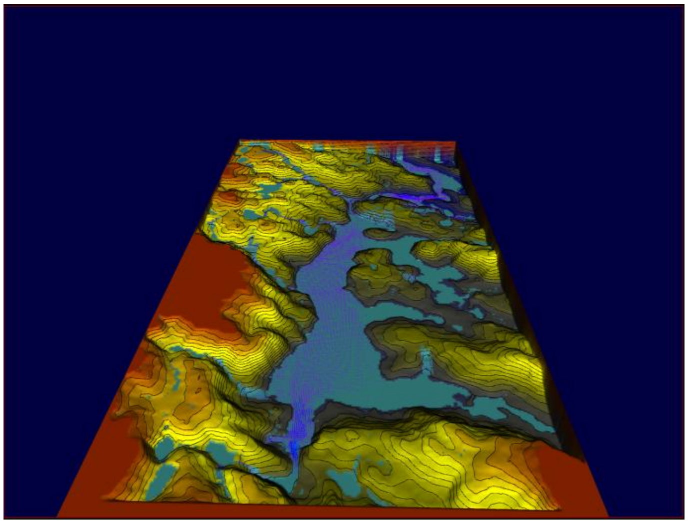

Fig. 7: Inundation map with rainfall in MIKE Animator for 3D visualization

VII. CONCLUSION

The work presented in this paper describes the significant capability of the MIKE FLOOD model integrated along with the GIS data's for improving the floodplain modeling capabilities. The area along the Wah Umkrah River where the study area is considered is a low lying area of Shillong. The study carried out consists of the field survey for the correction of the GPS points and the collection of various Remote Sensing and GIS data along with the hydrological data for the actual visualization of the flood event. The results generated shows little changes in the inundation map when the rainfall data along with the river discharge data is considered. As due to the variation in the terrain feature of the area, the rain water contributes to the inundation map of the flooded area along with the filling up of the streams and the terrain holes which were not seen during the simulation when the rainfall values were not considered. Hence this observation shows the contribution and variation in results when considering rainfall values during the flooding events

VIII. ACKNOWLEDGMENT

The authors express their sincere gratitude to Amaljit Bharali, Research Scientist North Eastern Space Application Center (NESAC) Meghalaya, India for his assistance in MIKE FLOOD simulation and to Dr. S. Sudhakar, Director (NESAC) for his constant encouragements to carry out Remote Sensing & GIS based projects useful for research and development studies.

REFERENCES

[1]. G. Drogue, L. Pfister, T. Leviandier, A. El Idrissi, J. F. Iffly, P. Matgen, J. Humbert, and L. Hoffmann, "Simulating the spatio-temporal variability of streamflow response to climate change scenarios in a mesoscale basin," *J. Hydrol., vol. 293, no. 1–4, pp. 255–269, Jun. 2004.*

[2]. Haile, A.T., and Rientjes, T.H.M., "Effects of LIDAR DEM Resolution in flood modelling: A model sensitivity study for the city of Tegucigalpa, Honduras",*ISPRS WG III/3, III/4, V/3 Workshop "Laser scanning 2005", Enschede, the Netherlands, September 12-14, 2005.*

[3]. Gianinetto, M.,Villa, P. and Lechi, G., "Postflood Damage Evaluation Using Landsat TM and ETM+ Data Integrated With DEM", *IEEE Transactions on Geoscience and Remote Sensing, Vol. 44, NO. 1, January 2006.*

[4]. Sequeira, V., Wolfart, E., Bovisio, E., Biotti, E. and Gonc¸alves, J. G. M., Hybrid 3D reconstruction and image-based rendering techniques for reality modelling. *SPIE 4309, pp.126–13, 2001.*

[5]. Debevec, P., "Image-Based Techniques for Digitizing Environments and Artifacts," Proc. 4th Int'l Conf. 3-D Digital Imaging and Modelling (3DIM 03), *IEEE Press, pp.234-242, 2003.*

[6]. Hakim. S. F. El, "Semi-automatic 3D Reconstruction of Occluded and Unmarked Surfaces from Widely Separated Views," *Proc. ISPRS Commission V Symp, Ziti Publishing, pp. 143-148, 2002.*

[7]. Kuo-Chung Wen and Tsung-Hsing Huang "The 3D Simulation Information System for Assessing the Flooding Lost In Keelung Basin". *Journal of Hydraulic Engineering, Vol. 132, No. 11, November 1* (2009)

[8] http://en.wikipedia.org/wiki/Shillong

[9]. Hammersmark, C.T, "Hydrodynamic modeling and GIS analysis of the habitat potential and flood control benefits of the restoration of a Leveed Delta Island*". Masters Thesis. University of California, Davis, California. 2002.*

[10]. Mishra, A. Anand, R. Singh and N.S. Raghuwanshi, "Hydraulic modeling of kangsbati main canal for performance assessment", *J. Irrig. Drain. Eng. 127(1), 27–34, 2001:*

[11]. Danish Hydraulic Institute. MIKE 11 Reference Manual, Appendix A: Scientific background, Danish Hydraulic Institute. Florshiem, J.L., Mount, J.F. Restoration of floodplain topography by sand-splay complex formation in response to intentional levee breaches, lower Consumnes River, Calafornia. Geomorphology. 2002:44, 67-94, 2000.

[12]. Colin Richard Robinson 12/16/2011 "Shallow Water Equations" PHY 307, SYRACUSE UNIVERSITY.

[13]. Moler, Cleve. "Chapter 18: Shallow Water Equations". Experiments with MATLAB, MathWorks. Web. <http:/www.mathworks.com/moler/exmchapters.html/>.