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14. ABSTRACT The following activities were completed, as per the project plan: 1. 3D and 2D camera placement problem: we also developed algorithms that identify faulty cameras. 2. Streaming 3D models and Quality of Service (QoS) in wireless networks: we addressed both rigid and deformable 3D models. 3. Tamper proofing and watermarking 3D models and motions.					
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Report Title

Final Report for Storage, Retrieval, and Delivery of 3D Models and Multi-attribute Motion Data

ABSTRACT

The following activities were completed, as per the project plan:

1. 3D and 2D camera placement problem: we also developed algorithms that identify faulty cameras.
2. Streaming 3D models and Quality of Service (QoS) in wireless networks: we addressed both rigid and deformable 3D models.
3. Tamper proofing and watermarking 3D models and motions.

Several new research results were obtained in the above areas (they are discussed in more detail in the Scientific Progress).

List of papers submitted or published that acknowledge ARO support during this reporting period. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

1. "Blind Robust Watermarking of 3-D Motion Data", P. Agarwal, and B. Prabhakaran, The ACM Transactions on Multimedia Computing, Communications and Applications (ACM TOMCCAP), Vol. 6(1), Feb. 2010 (To Appear - page info not available).
2. "Indexing 3D Human Motion Repositories for Content-based Retrieval", G. N. Pradhan and B. Prabhakaran, IEEE Transactions on Information Technology in BioMedicine, Vol. 13, No. 5, pp. 802-809, September 2009.
3. "On Supporting High Quality 3D Geometry Multicasting over IEEE 802.11 Wireless LANs", Hui Li, Ming Li, B. Prabhakaran, IEEE Transactions on Computers, Vol. 58, No. 4, pp. 558-571, April 2009.
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5. "Blind Robust Watermarking of Point Sampled Geometry", P. Agarwal, and B. Prabhakaran, IEEE Transactions on Information Forensics and Security, Vol 4, No. 1. Pp. 36-48, March 2009.
6. "Dynamic Priority Re-allocation Scheme for Quality of Service in IEEE 802.11e Wireless Networks", Ming Li, Hua Zhu, B. Prabhakaran, accepted for publication, ACM/Springer/URSI Wireless Networks (WINET). Published On-line February 2009, to be in print soon.
7. "Hand Gesture-based Computing for Hearing and Speech Impaired", Gaurav N. Pradhan, Chuanjun Li, B. Prabhakaran, IEEE MultiMedia Magazine, Vol. 15, No. 2, pp. 20-27, April-June 2008.
8. "Partial Fuzzy Query Resolution for Animation Authoring", Phani S Kotharu and B. Prabhakaran, ACM Transactions on Multimedia Computing, Communications, and Applications (TOMCCAP), Vol.4, Issue 2, Article 4, January 2008.
9. "Minimizing Collision Pairs Searched in Interactive Animation Authoring", Parag Agarwal, Srinivas Rajagopalan and B. Prabhakaran, The Visual Computer, Volume 24, Number 5, pp. 347-359, May, 2008.
10. "Motion Stream Segmentation and Recognition by Classification", Chuanjun Li, P. R. Kulkarni and B. Prabhakaran, International Journal of Multimedia Tools and Applications (MTAP), Springer, Vol.35(1), pp. 55-70, October 2007.
11. "Segmentation and Recognition of Motion Streams by Similarity Search", Chuanjun Li, S. Q. Zheng and B. Prabhakaran, ACM Transactions on Multimedia Computing, Communications and Applications (ACM TOMCCAP), Vol. 3(3), Article 16, August 2007.
12. "Middleware for Streaming 3D Progressive Meshes over Lossy Networks", Hui Li, Ming Li, B. Prabhakaran, ACM Transactions on Multimedia Computing, Communications, and Applications (TOMCCAP), Vol. 2, Issue 4, pp. 282 – 317, November 2006.
13. "Indexing of Motion Capture Data for Efficient and Fast Similarity Search", Chuanjun Li and B. Prabhakaran, Journal of Computers (JCP), Academy Publisher, Vol. 1(3), pp. 35-42, June 2006.
14. "End-to-end QoS Framework for Heterogeneous Wired-cum-Wireless Networks", Ming Li, Hua Zhu, Imrich Chlamtac, B. Prabhakaran, ACM/Springer Wireless Networks (WINET), Volume 12, Number 4, pp. 439-450, August 2006.
15. "Real-time Classification of Variable Length Multi-attribute Motion Data", Chuanjun Li, Latifur Khan and B. Prabhakaran, Knowledge and Information Systems: An International Journal (KAIS), Springer, Vol.10, No. 2, pp. 163-183, August 2006.

Number of Papers published in peer-reviewed journals: 15.00

(b) Papers published in non-peer-reviewed journals or in conference proceedings (N/A for none)

Number of Papers published in non peer-reviewed journals: 0.00

(c) Presentations

Number of Presentations: 0.00

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Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts): 0

Peer-Reviewed Conference Proceeding publications (other than abstracts):

1. Ziyang Tang, Guodong Rong, Xiaohu Guo and B. Prabhakaran, "Streaming 3D Shape Deformations in Collaborative Virtual Environment", accepted for IEEE Virtual Reality (VR) 2010.
2. "Tamper Proofing Mechanisms for Motion Capture Data", Parag Agarwal, and B.Prabhakaran, Proceedings of the 10th ACM Workshop on Multimedia and Security (Oxford, United Kingdom), pp. 91-100, September, 2008.
3. "A Robust Spectral Approach for Blind Watermarking of Manifold Surfaces", Yang Liu, B. Prabhakaran, Xiaohu Guo, Proceedings of the 10th ACM Workshop on Multimedia and Security (Oxford, United Kingdom), pp. 43-52, September, 2008.
4. "Fault Detection Framework for Video Surveillance Systems", J. Zhou, S. Ntafos, and B. Prabhakaran, Proceedings of IEEE Fifth International Conference on Advanced Video and Signal Based Surveillance, September 2008. pp. 219-226, AVSS '08.
5. "Loss Tolerance Scheme for 3D Progressive Meshes Streaming over Networks," Hui Li, Ziyang Tang, Xiaohu Guo, B. Prabhakaran, Proceedings of IEEE International Conference on Multimedia & Expo (ICME 2008), pp. 501 - 504, Hannover, Germany, June 2008.
6. "QOAR: Adaptive QoS Scheme in Multi-rate Wireless LANs", Ming Li, Yang Xiao, Hua Zhu, Imrich Chlamtac, B. Prabhakaran, Proceedings of IEEE ICC 2008, Beijing, China, pp. 2900-2904, May 19-23, 2008.
7. "Adaptive Frame Concatenation Mechanism for QoS in Multi-rate Wireless Ad Hoc Networks", Ming Li, Hua Zhu, Yang Xiao, Imrich Chlamtac, B. Prabhakaran, Proceedings of IEEE INFOCOM 2008, pp.1112-1120, Phoenix, Arizona, April 2008.
8. "Semantic Quantization of 3D Human Motion Capture Data Through Spatial-Temporal Feature Extraction", Yohan Jin and B.Prabhakaran, In Proc. Of International Multimedia Modeling Conference (MMM08'), pp 318-328. Kyoto, Japan Jan. 9-11, 2008.
9. "Content Based Querying and Searching for 3D Human Motions", Manoj Pawar, Gaurav N. Pradhan, Kang Zhang, B. Prabhakaran, Proceedings of ACM Multimedia Modeling Conference (MMM) 2008, pp. 446-455, Kyoto, Japan, January 9-11, 2008.
10. "An Integrated Mobile Wireless System for Capturing Physiological Data Streams during a Cognitive-motor Task: Applications for Aging", G. N. Pradhan, N. Engineer, M. Nadin, B. Prabhakaran, 2007 IEEE Dallas Engineering in Medicine and Biology Workshop, pp. 67-70, November, 2007.
11. "Robust blind Watermarking Mechanism for Point Sampled Geometry", P. Agarwal, B. Prabhakaran, Proceedings of ACM Multimedia and Security Workshop 2007 (MM&Sec 2007), pp. 175-186, September 2007, Dallas, TX, USA.
12. "Progressive Compression Invariant Semi-fragile Watermarks for 3D Meshes", Puneet Maheshwari, Parag Agarwal, B. Prabhakaran, Proceedings of ACM Multimedia and Security Workshop 2007 (MM&Sec 2007), pp. 245-250, September 2007, Dallas, TX, USA.
13. "On Supporting High Quality 3D Geometry Multicasting over IEEE 802.11 Wireless LANs", Hui Li, Ming Li, B. Prabhakaran, IEEE BROADNETS, September 2007.
14. "Design and Development of A Secure Real-time Monitoring, Control, and Coordination Systems for Intelligent Robot Swarms", Ming Li, Anthony Alvarez, Francesco De Pellegrini, Imrich Chlamtac, B. Prabhakaran, ACM/IEEE ROBOCOMM 2007, October 2007.
15. "Robust blind Watermarking Mechanism for Point Sampled Geometry", P. Agarwal, B. Prabhakaran, Proceedings of ACM Multimedia and Security Workshop 2007 (MM&Sec 2007), pp. 175-186, September 2007, Dallas, TX, USA.
16. "Progressive Compression Invariant Semi-fragile Watermarks for 3D Meshes", Puneet Maheshwari, Parag Agarwal, B. Prabhakaran, Proceedings of ACM Multimedia and Security Workshop 2007 (MM&Sec 2007), pp. 245-250, September 2007, Dallas, TX, USA.
17. "On Supporting High Quality 3D Geometry Multicasting over IEEE 802.11 Wireless LANs", Hui Li, Ming Li, B. Prabhakaran, IEEE BROADNETS, September 2007.
18. "Integration of Motion Capture and EMG data for Classifying the Human Motions", Gaurav N. Pradhan, Navzer Engineer, Mihai Nadin, Balakrishnan Prabhakaran, Proceedings of International Workshop on Ambient Intelligence, Media, and Sensing (AIMS) 2007, (held along with International Conference on Data Engineering (ICDE), April 20, 2007, Istanbul, Turkey.
19. "Data Hiding based Compression Mechanism for 3D Models", Hui Li, Parag Agarwal, Balakrishnan Prabhakaran, IEEE Data Compression Conference 2007 (DCC 2007).
20. "Shear Invariant 3D Model Retrieval", Sagar Naik and B. Prabhakaran Proceedings of International Workshop on Vision Geometry XV, edited by Longin Jan Latecki, David M. Mount, Angela Y. Wu, Proceedings of SPIE-IS&T Electronic Imaging, SPIE Vol. 6499, 64990A, January 2007.
21. "Hierarchical Indexing Structure for 3D Human Motions", Gaurav N. Pradhan, Chuanjun Li, Balakrishnan Prabhakaran, Proceedings of International Conference on Multimedia Modeling Conference (MMM) 2007, pg. 386-396, January 9-12, Singapore.
22. "Tamper Proofing of 3D motion Data Streams", Parag Agarwal, Balakrishnan Prabhakaran, Proceedings of 13th International Multimedia Modelling Conference 2007 (MMM 2007), Singapore, LNCS 4351 (Part 1) pp. 731-740, January 2007.
23. "Robust Blind Watermarking Mechanism for Motion Data Streams", Parag Agarwal, Ketaki Adi, Balakrishnan Prabhakaran, Proceedings of ACM Multimedia and Security Workshop, Geneva, Switzerland, September 26-27, 2006, pp. 230 - 235.
24. "SVD-Based Tamper Proofing Of Multi-Attribute Motion Data", Parag Agarwal, Ketaki Adi, Balakrishnan Prabhakaran, Proc. of The 12th International conference on Distributed Multimedia Systems (DMS), Grand Canyon, August 2006, pp. 46-52.
25. "Uncertainty: An Extra Layer of Security for Unauthorized Traffic based Web Services", Parag Agarwal, Balakrishnan Prabhakaran, Bhavani Thuraisingham, Proc. of The 12th International conference on Distributed Multimedia Systems (DMS), Grand Canyon, August 2006, pp. 52 - 58
26. "Motion Stream Segmentation and Recognition by Classification", Chuanjun Li, P. R. Kulkarni and B. Prabhakaran, Proceedings of the 31st IEEE International Conference on Acoustics, Speech, and Signal Processing(ICASSP 2006), pp. V-537- V-540, May 2006.
27. "A Novel Indexing Approach for Efficient and Fast Similarity Search of Captured Motions", Chuanjun Li and B. Prabhakaran, Proceedings of the 10th Pacific-Asia Conference on Knowledge Discovery and Data Mining (PAKDD 2006), pp. 689-698, April 2006.

(d) Manuscripts

Number of Manuscripts: 0.00

Number of Inventions:

Graduate Students

<u>NAME</u>	<u>PERCENT SUPPORTED</u>
Gaurav Pradhan	1.00
Duk-Jin Kim	0.25
Ziying Tang	0.50
Parag Agarwal	1.00
FTE Equivalent:	2.75
Total Number:	4

Names of Post Doctorates

<u>NAME</u>	<u>PERCENT SUPPORTED</u>
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

<u>NAME</u>	<u>PERCENT SUPPORTED</u>	National Academy Member
Balakrishnan Prabhakaran	0.20	No
FTE Equivalent:	0.20	
Total Number:	1	

Names of Under Graduate students supported

<u>NAME</u>	<u>PERCENT SUPPORTED</u>
FTE Equivalent:	
Total Number:	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

- The number of undergraduates funded by this agreement who graduated during this period: 0.00
- The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:..... 0.00
- The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:..... 0.00
- Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):..... 6.00
- Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:..... 0.00
- The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00
- The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields: 0.00

Names of Personnel receiving masters degrees

<u>NAME</u> Manoj Pawar Sagar S Shah Gyetae Park Sameer Agarwal Vivekshankar Ramaswamy Arun Prakash Total Number:	 6
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Names of personnel receiving PHDs

<u>NAME</u> Hui Li Parag Agarwal Junqiang Zhou Gaurav Pradhan Yohan Jin Total Number:	 5
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Names of other research staff

<u>NAME</u>	<u>PERCENT SUPPORTED</u>
FTE Equivalent:	
Total Number:	

Sub Contractors (DD882)

Inventions (DD882)

Summary of the Problem Studied

Content-based retrieval and delivery of 3D models and multi-attribute motion sequences facilitate several interesting applications for education and training of military personnel. It also can be helpful in providing the much needed coordination and support during field operations. These applications require integrated techniques for content-based retrieval and delivery of 3D data. For instance, layered representation of huge 3D models not only helps in progressive reconstruction on the client side during delivery over a network but also can help in efficient comparison during content-based retrieval from a 3D models repository.

The research goal of this project is to develop a theoretical framework for: (i) Verification of data from 3D sensor sources; (ii) Fault tolerant, secure placement of 3D sensors; (iii) Error concealment approaches for streaming 3D models; (iv) Streaming 3D data over wireless networks. Prototypes will also be built using the developed framework for specific applications.

Summary of Important Research Results

1. 3D and 2D camera placement problem

We identified the constraints that need to be obeyed for solving the problem of video cameras (both 2D and 3D). We also identified the issues in verifying whether a camera is malfunctioning. We developed strategies to identify and isolate faulty cameras. These strategies use both spatial position of cameras as well as the temporal sequencing of objects that appear in the camera outputs. This study was accepted for presentation in the 5th IEEE International Conference on Advanced Video and Signal Based Surveillance, Santa Fe, New Mexico September 1-3, 2008. An extended version of this paper is under revision for the journal: IEEE Transactions on Dependable and Secure Computing.

2. Streaming 3D models and Quality of Service (QoS) in wireless networks

We extended our error concealment approach for 3D mesh streaming to provide more accurate reconstruction of the meshes under lossy network conditions. This error concealment approach is able to work with multiple 3D compression schemes such as CPM (Compressed Progressive Meshes), PM (Progressive Meshes), and PFS (Progressive Forest Split). We also developed a scheduling approach for streaming 3D animations. This approach identifies the sequence in which 3D models have to be retrieved from a server based on the user's view of the animation (i.e., after identifying the 3D models that will be in user's view).

We carried out research on identifying QoS based issues for streaming multimedia data on wireless networks. Our research on concatenation mechanisms for multi-rate adhoc networks was presented in IEEE INFOCOM. An adaptive QoS framework was presented in IEEE ICC. Results related to streaming 3D models were published in IEEE Transactions on Computers, ACM Transactions on Multimedia (TOMCCAP), and other prestigious conferences. We also identified an efficient scheduling strategy for streaming 3D models and animations. 1 Phd thesis and a Masters' thesis were defended on this topic.

3. Tamper proofing and watermarking 3D models and motions

For tamper proofing and copy righting 3D models and motions, we identified that the main problem is formulating a cluster of data points. We developed approaches that will enable identification of data clusters. These data clusters can then carry watermarks either for tamper proofing or copyrighting. The results have been accepted for publication in IEEE Transaction of Information Forensics and Security as well as in ACM Multimedia & Security workshops in 2007 and 2008.

Bibliography

1. "Blind Robust Watermarking of 3-D Motion Data", P. Agarwal, and B. Prabhakaran, The ACM Transactions on Multimedia Computing, Communications and Applications (ACM TOMCCAP), Vol. 6(1), Feb. 2010 (To Appear - page info not available).
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