Indiana Telemedicine Incubator: A Multidisciplinary Consortium for the Development of Distributed Multimedia Database Technology for the Health Care Industry

Summary Project Progress Report for the 21st Century Research and Technology Fund, Round 1 Award

The Indiana Telemedicine Incubator (ITI) was established in February 2000 by a grant from the 21st Century Research and Technology Fund. It was created as a multidisciplinary consortium for the development of distributed, multimedia database technology for the healthcare industry. The main objective of the ITI project was to create a telemedicine research, development and delivery infrastructure by bringing together researchers, practitioners, educators, service providers, and product developers - to leverage the latest research and technology in multimedia databases and to foster economic development opportunities. The *incubation* of a specific set of technologies was proposed through the development of InterMed, a distributed, multimedia database system which would support (1) management and use of multimedia data, (2) annotation of medical video data with text and audio commentaries by physicians, (3) content-based search and retrieval of video data using indices built from the annotations, (4) image-based search and retrieval of video data using meta-data generated by image processing techniques, and (5) coordinated storage and retrieval of video data from remote sites. InterMed would exist as a permanent telemedicine facility, to be used as a test bed for future products. In particular, InterMed would be applied to three separate trial environments: medical education, remote diagnostic medicine, and clinical trial management. The ITI membership constituted a body of resources and expertise capable of producing such telemedicine products and services, and the firm establishment of ITI was intended to foster and perpetuate a center of telemedicine expertise that would continually generate new ideas, seek research funding, and attract world-class telemedicine researchers and companies to Indiana. ITI achievements in the three trial environments are described in this summary, beginning with our multidisciplinary research activities and emphasizing the cooperative efforts between consortium members that made the accomplishments of the ITI possible.

The principal scientific proposition driving the InterMed project was the development of complete and efficient database management capabilities for digital video libraries. The Video Database Management System (VDBMS) research project was launched to investigate the issues involved in the indexing, storage, access, query, search, retrieval and presentation (streaming playback) of digital video data, and to produce a viable video-enhanced database system. Major changes in the architecture and system components of a traditional text-oriented database system were required to implement video as a database object. Internal database storage and buffer managers and their operations were redesigned and re-implemented to handle the huge volumes of data with real-time constraints. New query types were introduced to take into account added video-related operations (query by image, multi-feature search) involved in generating, optimizing and executing query plans. To support the query and search of video content, innovative image-processing techniques were developed for producing the meta-data that identifies and describes video clips. The challenges of the video database research initiative produced a body of compelling research results: (1) video processing tools that employ scene cut detection to partition a video into clips, with MPEG7 compatible visual descriptors (features like color and texture) and high-level semantic descriptors (annotations and keywords applied to the video by domain experts), (2) a general high-dimensional index mechanism to handle extracted video features, (3) a new rank-join query operator to support queries based on multiple video features, (4) search-based buffer management techniques to support continuous media streaming, and (5) novel methods for managing video storage hierarchies (buffer, disk, tertiary storage). The VDBMS project culminated in the successful implementation of a viable video-enhanced research database platform.

Multimedia Delivery of Medical Education. The original ITI goal for a trial environment in medical education was the development of a prototype that delivered rapid classroom access to online, interactive multimedia medical materials for teaching and learning. The system was to support ad hoc video queries based on keywords assigned to video clips, returning representative (key) frames to identify selected clips, and providing quality streaming playback for retrieved video clips. The initial pre-processing of videos was to partition the video into "scene-based" clips, with corresponding keywords and annotations (meta-data) assigned by physicians. The development of this prototype was predicated on the success of four separate areas of inquiry: (1) the technology transfer of advanced multimedia functionality to the flagship database engine, TITANIUM, marketed by consortium member Micro Data Base Systems, Inc. (**mdbs**) which would serve as the underlying database, (2) joint efforts with Indiana University Centers of Medical Education to produce relevant, high quality medical education videos, compress them into MPEG format and apply semantic- and image-based processing to create appropriate medical meta-data to describe video clip content, (3) collaborations with faculty from the IU School of Medicine to determine user requirements and functional specifications, and (4) multidisciplinary applications-oriented research and development at Purdue University to create a viable prototype. The initiation, promotion and management of these cooperative efforts were carried out by the applications research group from Purdue University.

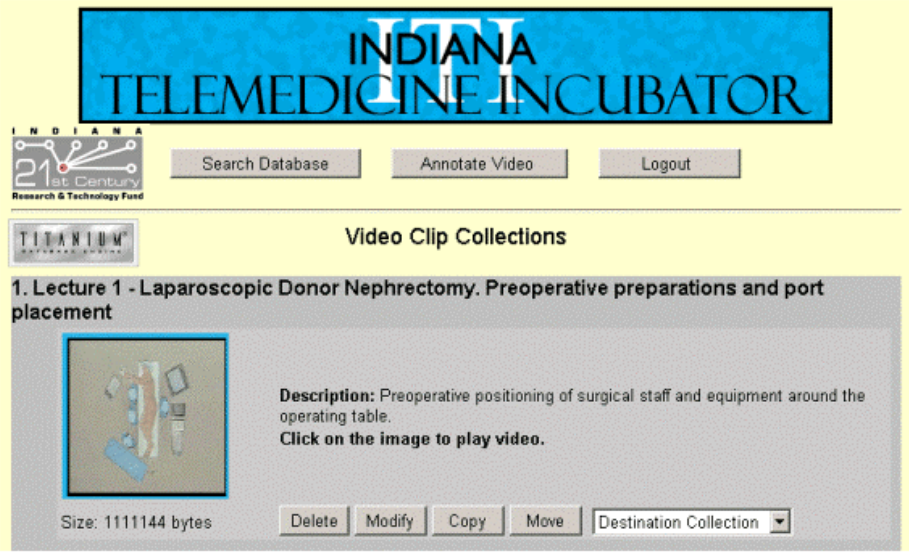

Figure 1. EduMed: online video clip collection for classroom browsing and presentation, with underlying video-enhanced TITANIUM database warehouse. The sample shows EduMed supporting a classroom presentation on laparoscopic donor nephrectomy.

The synthesis of this R&D work was the creation of EduMed: Web Video for Medical Education. The highly successful design and implementation of EduMed has created a commercially viable system that offers valuable medical education services that extend well beyond the original objectives. Demonstrations of EduMed to medical faculty and hospital groups have stimulated immediate and enthusiastic interest in applications with similar or expanded functionality, both for basic and continuing medical education. The Technology Transfer Initiative (TTi) of the Krannert Graduate School of Management is currently proceeding with a commercialization plan for EduMed. The cooperative process that evolved between the academic, commercial and medical sectors for the sharing of technology and expertise holds great promise for the continuation and expansion of research, development and delivery of medical applications based on distributed multimedia database technology. Specifically, the EduMed system provides web-accessible end-to-end services for the analysis, storage, access and retrieval of an indexed, MPEG-encoded medical video library. User-based security and access management allow faculty to prepare and deliver instruction through video query, retrieval and presentation, while allowing students to access fac-

ulty-created video collections for research, assignments and exams. A remote archive video server provides secure and efficient query, browsing and retrieval, allowing faculty users to save query results (clips) retrieved from the archive to local user warehouses in video clip collections. Local warehouse servers provide secure and user-friendly video shot collection access, management and high quality, streaming playback.

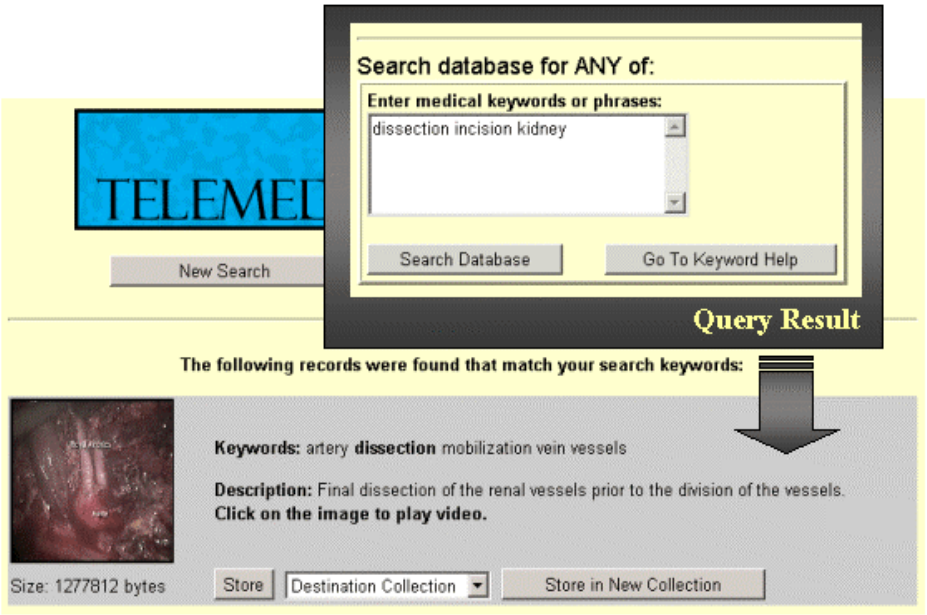

Figure 2. EduMed: online content-based keyword search and retrieval from a digital medical library, with underlying video-enhanced TITANIUM database archive. Medical keyword queries return representative (key) frames for clips with matching keywords.

Partner Roles, Interactions and Accomplishments. While academic, commercial and medical sectors leveraged federal and institutional funding to promote ITI activities, the cross-sector interactions to develop EduMed were funded entirely by the 21st Century Research and Technology award. The remarkable results of these interactions are now described. Contents of the digital medical library for EduMed were produced through the consistent and conscientious efforts of Creative Services at the IU School of Medicine, with valuable annotations and content-based clip and keyword identification developed by medical domain experts and physicians. Continued cooperative sessions with medical faculty at the IU School of Medicine supplied Purdue University's applications research group with the necessary medical knowledge, classroom scenarios, and faculty user requirements. The sessions also provided us with occasions to present medical faculty with new ideas about the unprecedented opportunities and benefits to healthcare offered by enabling technologies in distributed multimedia databases. The EduMed prototype produced by these discussions has been enthusiastically received, not only by faculty at the IU School of Medicine, but also by other medical groups who envision similar applications that serve their needs. These groups have requested partnership in the continuation and expansion of applications based on distributed multimedia database technology and, in particular, on the EduMed application. The investigation, implementation and integration of advanced multimedia capabilities into the TITANIUM database engine was accomplished through a dedicated, joint effort between the multimedia database research group at Purdue University and the R&D professionals at **mdbs.** The research group at Purdue University established a policy whereby research results, algorithms, and code produced for the advancement of multimedia databases, would be made available without restriction to the **mdbs** R&D group. Similarly, **mdbs** shared their code for video-enhanced TITANIUM functions with Purdue University's applications research team for integration into the EduMed prototype. Joint R&D sessions and the exchange of code culminated in the successful transformation of TITANIUM from a text and number processing database engine to a database that supports video management capabilities, including access, query, retrieval and presentation. As

a result of this project **mdbs** also developed a Solaris version of their database software, giving them access to a large, lucrative market requiring Solaris support. For **mdbs**, the increased presence of their product line in the medical community, the increased market appeal of a video-enhanced database product, and the new Solaris version of TITANIUM have already generated commercial benefits. The **mdbs** website prominently features its key role in the ITI project, highlighting the development of medical multimedia database servers based on TITANIUM technology. TITANIUM for Solaris is now in use at C-SPAN Archives.

Remote Diagnostic Medicine. The ITI goal for the trial environment in remote diagnostic medicine was the development of a support system in physician-shortage areas for transmission of medical data and consultation information. Physicians and healthcare facilities would benefit significantly from the efficient capture, transmission, viewing and sharing of medical data, with guaranteed image quality, speed, reliability and security. Physicians from Methodist Hospital and Clarian Health are formulating and guiding a prototype teleconsultation project to connect Greene County Hospital for remote cardiology "examination and interview". Clarian Institutional Review Board recently granted approval for use of teleconsultation equipment, sanctioning the detailed specifications for the trial research project entitled "Management of Congestive Heart Failure using Teleconsultation". The next phase involves collection and analysis of data. Physicians will "examine and interview" each patient using teleconsultation once per month.

This trial was approved for support by the Showalter Fund, to provide data collection, nursing support, and statistical support. The equipment purchased through the 21st Century Research and Technology award is in place and operational. The audio video connection between Greene County and the cardiology office has been successfully tested, and tele-stethoscopes and ear-eye scope attachments to the equipment are installed at both ends. Nurses and administrators have been trained (via teleconference) in the use of the equipment. The following administrative issues remain: Indiana Medicare funding (Medicare will not initiate funding for teleconsultation until October 1), the securing of research nurse time and training, the form and process for data collection, and the strategy for patient scheduling. These issues are being resolved. The Greene County Hospital equipment and the office receiving station of Dr. James Trippi, MD will be used in the immediate future for routine office follow-up appointments, and the research trial will begin shortly thereafter. As a result of the installation of advanced tele-diagnostic equipment, negotiations with the Indiana Correctional System are currently underway to provide remote cardiology teleconsultation for inmates. Several inquiries for press coverage have been made; this will be arranged through the Clarian Health marketing department.

Clinical Trial Management. The ITI goal for the trial environment in clinical trial management was to facilitate "store and query" for field clinical trial data. Information content and functional specification of the prototype were supplied by Med Institute, Inc, a consortium member that provides medical device evaluation, clinical studies and medical product development. The application of multimedia database server functionality to support clinical trial data access was led by multidisciplinary research groups at Purdue University. Specifications for a web-based prototype included the following online capabilities: patient enrollment, submission of images for measurements, automatic image measurements, storage of image and measurement, viewing of images with image control (contrast, brightness, etc), access to multimedia patient dockets (images, forms, reports, data), and image searches based on selected image characteristics.

Current research efforts are focused on the development of enhanced image segmentation and feature extraction techniques. Since a medical image (e.g., MRI, CAT scan) stores an enormous amount of information content related to different parts of the human body, medical information extraction requires robust image processing techniques to describe selected objects contained in the image or region of the image in their entirety. Our objective was to extract an accurate representation of the contents from a collection of

images, and to classify the images based on features and contents. This corresponds to two areas of inquiry: (1) image segmentation/labeling, and (2) feature extraction. Segmentation algorithms enhance different regions of the underlying image based on color, texture and gray level. To facilitate the search for the objects of interest in the image, morphological filtering was applied to smooth object outlines and eliminate small projections. This process preserves absolutely the geometry of objects of interest. The features for salient objects were selected for study, including diameter (max, min), centroid, area, orientation, perimeter, and thinness. When the investigations related to image processing techniques are complete, the clinical trials prototype will be developed using the storage, query, access and retrieval techniques developed through the VDBMS research project. The web-based implementation of the prototype will use video-enhanced TITANIUM as the underlying database. Some additional database enhancements will be required, such as the integration of the required capability to support queries for image similarity matching.

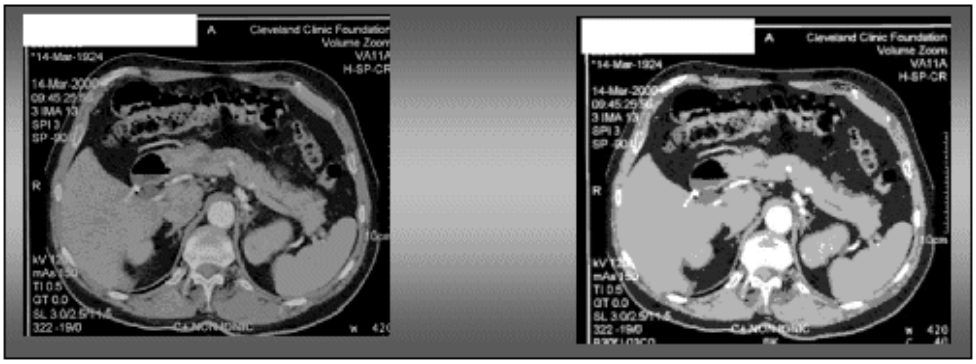

Figure 3. Original image (left). Segmented image (right). The PCT/median technique was used for segmentation; it outperformed all other segmentation algorithms for the clinical trial image objects.

Expectation of Success. The prototype trial environment for medical education, EduMed, has already achieved the goals set forth in the ITI proposal, although the commercialization process, demonstrations to the medical community and discussions of new opportunities continue at a rapid pace. Further advancements to EduMed are underway, focusing on support for visual feature extraction and image-based queries, along with the required supporting database enhancements to TITANIUM. The VDBMS project will provide the research base for technology transfer in this next phase of video enhancements. In addition, the restructuring of EduMed as an intelligent, integrated portal to distributed mixed-media data for medical education is proposed in this expansion request for 21st Century Research and Technology funding. The trial environment for remote diagnostic medicine in the management of congestive heart failure is ready to begin teleconsultation appointments. Evaluation of the effectiveness of this trial project, as well as promotions of other teleconsultation trials will continue. The synergy between the clinical trials management prototype and EduMed is a strong indicator of success in the clinical trial environment. Research efforts in the development of image segmentation and feature extraction techniques continue, as the implementation of the system for web-based clinical image data storage, access, query and retrieval begins.