Government of Canada Gouvernement du Canada

Canada

Research Portal

Application - Research Tools and Instruments

Identification

Applicant

Family Name: Deluzio

First Name: Kevin

Middle Names: John

Current Position: Professor

Administering Organization

Organization

Queen's University

Department/Division

Mechanical and Materials Engineering

Application

Application Title

Markerless motion capture equipment for the development of a multi-centre biomechanical analysis tool

Language of the Application

(•) English ( ) French

Suggested Evaluation Group

1512 Mechanical Engineering

Hours per month to be devoted to the research/activity, or use of equipment or facility

40

Summary of Proposal

Summary

Human movement researchers across Canada have an opportunity to reimagine what data collection looks like with innovative new technology. Using a machine learning-based markerless motion capture system that extracts biomechanical data from synchronized videos, we are developing the next generation of biomechanical analysis tools. This equipment grant will support the purchase of the optimal video camera systems for markerless motion capture. One system will be used in the Human Mobility Research Laboratory of Dr. Kevin Deluzio, who is an experienced human motion researcher and a pioneer in the adoption of markerless technology. Two additional systems will be a set of mobile systems for our collaborator and for remote site data collection. This will allow us to take a motion capture lab to any site. The result will be the most cost-effective and least invasive way of collecting human movement data. By removing physical barriers to data collection, we can partner with our collaborator Dr. Janie Wilson at the Dynamics of Human Motion Laboratory at Dalhousie University to do multi-site biomechanics research. Markerless motion capture provides a feasible way to collect biomechanical data with a level of reliability that is not achievable by legacy technologies, unlocking the potential to collect these data at an epidemiological scale. Building biomechanical analysis tools from large datasets collected on diverse populations, including individuals with musculoskeletal diseases, will ensure the development of robust and effective tools. This type of research on vulnerable patients has been severely limited by the nature of the preceding marker-based technology and underscores the forthcoming expansion of human mobility research resulting from this new technology.

This research (currently supported by NSERC-DG and NSERC-CRD grants) will be severely impacted by a delay in acquisition of equipment as the requested camera systems will replace existing equipment that is not suitable for the proposed work due to limits in the area that can be recorded. Over the next five years it is projected that 50 HQPs will use these systems in addition to the 8 current post-graduates that have research planned and ongoing working with the system.

Markerless motion capture marks a major advancement in the field of biomechanics and will have an incredible impact on both the progression of fundamental research and the application of this research to musculoskeletal diseases, clinical movement disorders, injuries, and athletic performance. By supporting the purchase of markerless motion capture video camera systems, the Human Mobility Research Laboratory in partnership with Dynamics of Human Motion Laboratory will lead the way towards the development of biomechanical analysis tools that can be used for future translational research.

Second Official Language Translation

Proposed Expenditures

	Year 1 Amount
Equipment or facility	
Purchase or rental	$114,635
Subtotal	$114,635
Other (specify)	
	$0
Subtotal	$0
TOTAL PROPOSED EXPENDITURES	$114,635
Total Cash Contribution from Industry (if applicable)	$0
Total Cash Contribution from University (if applicable)	$0
Total Cash Contribution from Other Sources (if applicable)	$0
TOTAL AMOUNT REQUESTED FROM NSERC	$114,635

Activity Details

Certification Requirements

Does the proposed research involve humans as research participants? (●) Yes ( ) No

Does the proposed research involve animals? ( ) Yes (●) No

Does the proposed research involve human pluripotent stem cells? ( ) Yes (●) No

Does the proposed research involve harzardous substances? ( ) Yes (●) No

Impact Assessment

Will any phase of the proposed research take place outdoors? ( ) Yes (●) No

Research Subject Codes

Research programs to be supported by the equipment

This NSERC-RTI proposal will accelerate the development of the next generation of biomechanical analysis tools by supporting the purchase of **markerless motion capture video camera systems for mobile applications and collaborative research**. In combination with novel computational methods, these camera systems have the potential to significantly change the capabilities of the **Human Mobility Research Laboratory (HMRL)** of **Dr. Kevin Deluzio** and will develop tools to enable the expansion of human motion research by facilitating collaborative research and expanding into new fields. Our collaboration with co-applicant, **Dr. Janie Wilson** at the **Dynamics of Human Motion Laboratory (DOHM) at Dalhousie University,** highlights this approach.

The **Deluzio** research program (currently supported by an NSERC-DG and NSERC-CRD) has had wide success in developing tools for the analysis of human motion using advanced statistical techniques and modelling approaches. However, the full potential of these methods has been limited by challenges with the underlying motion capture technology. Standard motion capture equipment requires reflective markers to be attached to body landmarks and recorded with infrared cameras. This has severely limited the accessibility of human motion data, hindered multi-centre studies, and limited eventual translation of quantitative methods into the clinical realm.

To address this knowledge-application gap, standard motion capture must be revolutionized. Markerless motion capture does this by challenging the fundamental assumptions of the equipment required to perform this work and shifts the focus to novel methods by which anatomical features are identified. By using small off-the-shelf video cameras that are a fraction of the cost of traditional optoelectronic motion capture cameras, a major barrier to widespread research use and clinical uptake is removed. By eliminating the need for surface markers, there is no longer a need for physical contact with research participants, thereby expanding to situations where the use of markers was an impediment to research. Expert examiners are no longer required to palpate anatomical landmarks, removing operator bias and making it so that quality data has been democratized to any user. This democratization of quality human movement data enables high volume and high veracity data science explorations in biomechanics.

The compilation of multi-centre data represents the next step in advancing the study of biomechanics and one that is only possible with markerless motion capture technology. Biomechanical data collected using traditional technologies are highly sensitive to both to the expertise of the operator and the lab in which they were collected in. This sensitivity has severely limited data sharing and multi-centre research. Markerless motion capture is much more robust against these effects, due to a lack of marker placement and its associated poor reliability. This allows for data from multiple sites to be easily aggregated, finally allowing biomechanical research to benefit from the power of large sample sizes and the application of advanced data analytics and machine learning algorithms.

Our preliminary work with the markerless motion capture system has been compelling. Funded by the NSERC-CRD we have completed and published three validation studies [1-3]. This validation work not only demonstrated equivalent kinematic measures, but reduced inter-visit variation compared to marker-based motion capture. The flexibility of the data collection will vastly expand the types of human motion that can be quantified and allow this to be done in naturalistic settings. Additionally, markerless motion capture data will serve as the foundation to develop new tools such as estimating joint kinetics without requiring force platform recordings. Beyond gait analysis, markerless motion capture facilitates the expansion of biomechanics research into other movements and disease applications.

To prove the case that markerless motion capture will enable multi-centre research, our national collaborator has the expertise and resources to collect parallel data at an additional site.

Dr. Wilson at Dalhousie University (currently supported by an NSERC-DG) researches gait biomechanics in osteoarthritic patients to understand the role of mechanical factors in disease progression and treatment response. Additionally, Dr. Wilson has previously implemented marker-based motion capture into an orthopaedic clinic at St. Joseph's Hospital in Hamilton and has first-hand experience of the limitations of those systems in clinical environments and has identified markerless motion capture as a solution. This collaboration is important because it will allow us to collect data on similar target populations, doubling data collection capacity. A scalable data sharing infrastructure will be created and will easily allow additional collaborators. Dr. Wilson's leadership role in other collaborative research initiatives, including GaitNet (through the MSK Rehabilitation Research Network) and the Canadian Longitudinal Study on Aging, will be vital in facilitating the collaborative research piece and promoting the further adoption of new sites.

Equipment requested

Three identical markerless motion capture video camera systems are requested: one for each of the research groups (HMRL and DOHM), and an additional portable system can be easily transported for temporary installation with additional collaborators. Each system includes 8 video cameras with control boxes (Sony RX0 II), and an ethernet switch to connect and synchronize the cameras. The synchronized video data collected by the camera system is the raw data used by the markerless motion capture software (Theia3D, Theia Markerless, Kingston ON) to estimate the 3D pose of the humans visible within the captured videos. The basis of the pose estimation algorithm is a deep neural network which was trained on >500,000 images of humans in everyday contexts to estimate the position of specific anatomical landmarks of the humans within those images. This training enables the neural network to estimate the position of those anatomical landmarks in any new image or series of images (i.e. video). The markerless motion capture software uses these landmark position estimates from multiple synchronized and calibrated 2D videos to produce estimates of the 3D pose of all humans within the images. The markerless system's use of video data enables pose estimation to be performed with minimal restrictions on the clothing of human subjects, the environment in which the data is collected, and the action that is being performed.

Need, urgency, suitability of equipment

The markerless motion capture video camera systems that will be purchased have previously been tested by our industry partners and ourselves (via an equipment loan from our industry partners). This testing has proven that these cameras are the most suitable for our requirements as they provide sufficient depth of field and resolution to collect data in the large data capture volumes required to assess a variety of mobility tasks. Additionally, the user-interface is straightforward, reducing barriers to uptake. Having compared multiple camera systems in the field (including Qualisys Miqus video cameras and OptiTrack Prime Color video cameras), we are confident that the proposed camera systems specified are ideal for our data collection needs. An additional benefit of these cameras is their reasonable cost. As these are not research-specific cameras and are widely commercially available, the cost of this complete markerless motion capture system is a fraction of the cost of a traditional marker-based motion capture system. There are no other camera systems currently available at our institution that meet our needs.

The specified camera systems are needed urgently because the current Qualisys Miqus video cameras pre-existing in the lab and originally intended for this research program were found to be insufficient due to their limited depth of field and resolution. The Miqus cameras are only able to capture video data for a constrained treadmill configuration. Our current equipment loan from industry partners that has allowed us to test the cameras is ending.

The need for portable camera systems that can be deployed to multiple remote sites is dictated by many factors. Firstly, collecting data at multiple sites simultaneously, vastly increases the total number of individuals that can be collected. Large sample sizes are necessary to develop accurate and impactful analytical tools. Secondly, to develop robust biomechanical analysis tools, we need to collect data on individuals across a wide range of mobilities. Having a system that can be easily deployed to facilities that specialize in the treatment and assessment of certain conditions, but do not have the technology to collect these data, makes this possible and efficient. Additionally, by setting up at remote sites, we can eliminate the need for vulnerable individuals to travel to a laboratory. And finally, to characterize biomechanics at the population level it is important to obtain a reference sample of individuals with no known impairments for comparison. Recruitment of these individuals through hospitals or research laboratories is inefficient and a barrier to large sample collection. Having a portable system that can be deployed into real-world environments is crucial to be able to collect data on these individuals. All systems can be set up in locations outside of standard laboratories for use in performing remote data collections and do not require special facility requirements (only a single standard electrical outlet). As markerless motion capture is the current focus of the lab, with hundreds of planned data collections to fully test the system and develop robust tools, these systems will be used at full capacity.

The proposed camera systems represent an extremely cost-effective platform to allow the continued development of biomechanical analysis tools. With the future advancement of these analysis tools, combined with the accessibility of the camera equipment, there is an opportunity to have a significant impact on biomechanical research and developing tools that may have future clinical use.

Importance of equipment for training highly qualified personnel (HQP)

The camera systems will be used extensively by graduate and undergraduate students as well as postdoctoral research fellows and technicians. The **Deluzio** research group currently has 8 post-graduate trainees, mostly with engineering backgrounds, who are actively engaged with markerless motion capture projects. The **Wilson** research group currently has 6 active graduate students, primarily with engineering backgrounds in an inter-disciplinary research environment. The research collaboration between Queen’s and Dalhousie Universities provides an important opportunity for graduate students to be involved in research at both sites. Through these collaborations, the involvement of approximately 50 HQPs is projected for the next 5 years.

The requested camera systems will be fundamental to allow trainees to collect the raw data necessary for the development of biomechanical analysis tools. Research by a former graduate student identified the shortcomings of the previous cameras in the laboratory and current students have been responsible for verifying that the proposed camera system meets our requirements.

The ease of use of the proposed camera systems will radically improve the throughput of the lab, and the scope of the data that we will be able to collect will expand the learning opportunities for HQP. Trainees are involved in all aspects of their research projects including defining research objectives, performing hands-on data collections, analyzing data, preparing publications, and presenting their own findings at conferences. These HQP will work on interdisciplinary projects, benefiting from exposure to multisite research with collaborators. They will train in state-of-the-art movement analysis labs. They will gain skills in specific areas including: data collection hardware (motion capture, electromyography, accelerometry, force transducers, and load cells), software for data analysis (MATLAB, SAS, R), and modelling (MATLAB, multibody dynamics), experimental design, analysis of multivariate time-series data, and optimization, and of course this emerging technology of markerless motion capture. The HQP are also trained in problem solving skills, critical thinking, and communication skills in a multidisciplinary environment that encourages excellence. The nature of the markerless motion capture data collections will lead to significantly increased sample sizes which will allow students to learn and apply advanced statistical techniques such as principal component analysis and unsupervised machine learning approaches such as cluster analysis. In the current climate of big data and personalized medicine approaches, these will be valuable and extremely transferable skills. The much larger dataset will allow us to include considerations of diversity and bias in our analyses, which are critically important in the development of any technology that relies on supervised machine learning approaches such as the neural network used to build the markerless software. Training HQP to recognize these considerations in their research is critical to building robust research tools and informed researchers. Recognizing the issues of equity, diversity, and inclusion (EDI) are also important to the makeup of the research team. The major users of the equipment are the graduate students and we strive for an inclusive research team by actively seeking applicants from diverse backgrounds and considering individual circumstances when developing personalized training plans and mentoring activities. At a lab group level, we participate in international initiatives highlighting inequity (including ShutDownSTEM and National Day for Reconciliation, formally Orange Shirt Day) and have committed to ongoing monthly discussions of these issues. Additionally, the institutions have programs supporting Black, indigenous, and female engineering students, in recognition of historic and ongoing inequities.

References

1. Kanko, R.M., et al., *Concurrent assessment of gait kinematics using marker-based and markerless motion capture.* J Biomech, 2021. **127**: p. 110665.
2. Kanko, R.M., et al., *Assessment of spatiotemporal gait parameters using a deep learning algorithm-based markerless motion capture system.* J Biomech, 2021. **122**: p. 110414.
3. Kanko, R.M., et al., *Inter-session repeatability of markerless motion capture gait kinematics.* J Biomech, 2021. **121**: p. 110422.

Equipment Details

Camera Systems (3): Each of the proposed camera systems for markerless motion capture consists of eight Sony RX0 II cameras (15.3 megapixels, 4K at 30fps, up to 1000 fps), eight Sony Camera Control Boxes, a gigabit ethernet switch, and eight CAT6 ethernet cables to connect all parts of the system. The budgeted cost is based on the quote from Camera Kingston due to lower cost than quote from Theia Markerless for these components. High capacity SD memory cards from Theia Markerless are included in the budget. Mounting hardware for the cameras is also included (the cost from the Theia Markerless quote is used because it is less expensive than from online retailers). The first system will be housed in the Human Mobility Research Laboratory (Kingston) for predominantly in-lab data collections. The second system will be transported to our collaborators in Halifax. The third system will be a dedicated portable system. This system will be transported to other identified sites in Kingston including Providence Care Hospital and select locations on Queen's University Campus for multi-environment testing. This system will also be deployed to new collaborators as required. The anticipated minimal costs for transportation to collaborators will be covered by existing operating or travel funds.

Laptop (1): The proposed laptop is an Asus M509DA-SS51-CB 15.6-inch Notebook which includes all required specifications for the collection of data at remote locations (e.g., out of laboratory environments). The specifications include one 512GB Solid State drive and 8GB of RAM. These specifications will not allow processing to be completed on this laptop but they are sufficient to collect the data and transfer it to the custom desktop that will be used for processing. The laptop will be purchased from the Queen's preferred vendor, Dell.

Markerless Motion Capture Software Licence and Maintenance Fees (1): This license is required for the system being sent to our collaborating site to allow for on-site processing of markerless video data. The maintenance fees allow access to the newest version updates to the software and support. Only 1 licence is required because licences (partially in-kind) are currently provided by Theia Markerless to HMRL as part of an existing grant (ORF grant described below). Theia Markerless is the sole source provider of their software.

Custom Desktop Computers (2): The proposed custom desktop computer is required for the storage and processing of high-quality video data using the markerless motion capture software provided by our industry partners. The markerless motion capture software requires a computer with at least one NVIDIA RTX 2080ti GPU, 32GB of RAM, and one octa-core i9 processor. A solid-state drive with at least 4TB of storage is required to allow video files to be saved and accessed quickly, and to provide ample short term data storage. The computer and connectors quoted by Theia Markerless are included because they provide custom configured computers and the cost is comparable to other suppliers.

Managed Server (1): The proposed server will be hosted and managed by the Center for Advanced Computing (CAC) located on Queen's University Campus. The CAC specializes in secure advanced computing resources and support for Queen's researchers. The server cost is to fund the procurement of hardware that the CAC identifies, installs, and manages. The server will be a secured centralized storage location for all local and multi-centre data.

Item	Quantity	Cost per unit in original currency	Exchange rate	Total cost in Canadian dollars
Sony RX0II Camera System with Peripheries (supplier: Camera Kingston) • **8x** cameras + control boxes + cables + adapters • **1x** ethernet switch	3	$13,323	1	$39,969
Set of memory cards for camera system (supplier: Theia Markerless) • **8x** cards ($199 USD each)	3	$1600	1.2329	$5,918
Camera Mounting equipment kit (supplier: Theia Markerless) • **8x** MANFROTTO 808RC4 STANDARD 3-WAY HEAD gimbals ($169 USD each) • **8x** Manfrotto Black Triman Camera Tripods ($179 USD each)	3	$2,784	1.2329	$10,297
Custom Desktop Computer ($6100 USD each) + cables ($30 USD per computer) (supplier: Theia Markerless)	2	$6,100	1.2329	$15,115
Laptop computer (supplier: Dell)	1	$649	1	$649
Theia software license ($28,000 USD) + 1 year support ($3500 USD) + service fee ($3200 USD) - discount of $7000 USD (supplier: Theia Markerless)	1	$27,700	1.2329	$34,151
Managed server (supplier: CAC at Queen's University)	1	$4756	1	$4756
Subtotal:				$110,855
Institutional tax rate (%):				3.41%
Total tax:				$3780
Total cost:				$114,635
Total confirmed from other source(s):				$0
Total requested from NSERC:				$114,635

Relationship to other research support

There is no overlap between currently held funding and the funding requested to purchase the video camera systems for markerless motion capture, as detailed below.

Dr. Kevin Deluzio Natural Sciences and Engineering Research Council of Canada (NSERC) Collaborative Research and Development (CRD) Grant ***Extending 3D markerless tracking for biomechanics analysis of human gait*** ($240,000.) Salaries for HQP and a small amount for conference travel are the only budget items in this grant.

Ontario Research Fund (ORF) ***Translating knowledge on brain function into next generation technologies for neurological assessment*** (PI: Dr. Stephen Scott). This large grant includes a portion for the development of motion capture-based assessment of mobility within a circuit for clinical assessment (Research Theme 2C: Gait, Mobility and Postural Control) with **Deluzio** as the project lead of this component ($223,000). The funding covers HQP salaries and software (after a significant in-kind contribution by the industry partner) but does not include funding for these cameras, therefore there is no overlap with the current RTI.

Dr. Kevin Deluzio Natural Sciences and Engineering Research Council of Canada (NSERC) Discovery Grants Program (DG) Grant ***Tools for the biomechanical analysis of human movement: Application to knee osteoarthritis*** ($230,000) This grant covers HQP salaries and travel expenses with a small equipment maintenance budget. There is no overlap with the proposed RTI.

Dr. Janie Wilson's Natural Sciences and Engineering Research Council of Canada (NSERC) Discovery Grants Program (DG) Grant
Scalable Biomechanical Modeling of Joint and Muscle Forces in the Study of Knee Osteoarthritis ($250,000) funds primarily HQPs and has no equipment overlap with the current RTI.