Warfighter Digital Twin

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ABSTRACT

Digital Engineering Strategy was initiated in 2018 and has been pursued within the United States Department of Defense enterprises since then, with the goals to promote the use of digital representations of systems and components and the use of digital entities as a technical means of communication across a diverse set of stakeholders. Since Warfighters are the most valuable military assets, the digital representation of individual Warfighters will become an indispensable part of military digital engineering. When advanced digital technologies are used to protect, enable, and empower Warfighters, the unique characteristics of an individual Warfighter must be accounted for. Therefore, it is highly advantageous to build a 'digital twin' for an individual Warfighter.

In this paper, the concept of Warfighter Digital Twin (WDT) is proposed, defined as the digital replica or virtual copy of a Warfighter. A framework is developed for building a WDT, which employs physics-based, individualized, and unified human models. These models are combined with data containers with data analytics to describe and represent personal physical, biological, and physiological features and status. A process is developed to efficiently create a WDT. The potential applications of the WDT are explored, including individualized military products and devices, adaptive accommodation, Warfighter performance monitoring, among others. The WDT technology can be employed within synthetic training environments for mission planning with small, specialized groups. A preliminary WDT application is demonstrated in a simulation monitoring the individual Warfighter physiological status during marching in a user-defined environment. The Warfighter physiological status is predicted based on individual biomechanics and metabolic energy expenditure.

ABOUT THE AUTHORS

Dr. Zhiqing Cheng is the founder and president of Innovision, LLC., a start-up company focusing on developing technologies related to human digital twins and using these technologies for human-centered products, services, and performances. He had worked at Wright-Patterson Air Force Base as an on-site contractor from 2001 to 2017, providing support to the Air Force Research Laboratory on human performance and protection. He was the principal investigator and program manager of the contract for the AFRL's Human Measurement and Signature Intelligence (H-MASINT) program from 2012-2017. He has vast research and development experience in the areas of digital human modeling and simulation, artificial intelligence and machine learning, computer vision, and structural vibration. He has assumed numerous R&D projects as the principal investigator and published over 100 technical papers as the lead author.

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INTRODUCTION

A 'Digital Twin' is a virtual representation or digital form of a physical object or process in the real world. The digital twin technology has been widely implemented by industry in recent years (Grieves 2021). As the real world is centered around the human, the digital representation or virtual self of the human should be at the center of the digital world. This basic consideration motivated the concept of the Human Digital Twin (HDT) and Warfighter Digital Twin (WDT) developed at Innovision (Cheng 2019). The WDT developed by Innovision is based on individualized human models combined with personal data containers linked to sensors. The data can be processed using analytics to provide an integrated, dynamic representation of one's personal physical and physiological state. Combined with physics solvers, a WDT can be used to perform physics-based analysis, simulation, and prediction of physical and physiological performance of an individual Warfighter (Cheng et al., 2020).

Digital Engineering Strategy was initiated by the United States Department of Defense in 2018 and has been pursued within military enterprises since then, with the goals to promote the use of digital representations of systems and components and the use of digital entities as a technical means of communication across a diverse set of stakeholders. Since Warfighters are the most valuable military assets, digital representation of individual Warfighters will become an indispensable part of military digital engineering. When advanced digital technologies are used to protect, enable, and empower Warfighters, it is advantageous to build a digital twin for a Warfighter to represent one's unique characteristics.

In this paper, we will present our development of WDT technology, including concept formation, construction, potential applications, current limitations, and prospects. As a practical example of use of WDT, we will present a study performed to use WDT for individual Warfighter physiological status simulation and prediction.

WDT CONCEPT FORMATION

Basic Considerations

1. Traditional human models have two major limitations: (a) Each describes a single aspect or small set of human features/characteristics; and (b) They typically describe the average properties of a human. Often, one model is used to represent a group or population. Humans, however, embody a complicated system with distinct characteristics ranging from physical, biological, and physiological features to cognitive and behavioral traits. Though a complete digital representation of human is still far from reality, a unified representation of multiple features of human with a high level of details and fidelity is possible due to rapid advancement of digital human modeling and computer technology in recent years. Conventionally, human body shape (with anthropometry), musculoskeletal characteristics, and anatomy are described separately by three independent models with different data representations. However, human features/characteristics are inter-dependent. It is advantageous that they be described in a unified way, if possible, so that the unification can more accurately describe a human. Particularly, human body shape, musculoskeletal characteristics, and anatomy all embody human physical features and lend themselves to the unified modeling.
2. Humans share common gender-specific anatomy and gross physical attributes. Therefore, we can create a unified model structure and data structure and standard models (templates) that will be used for all humans. Humans' differences make each of us unique and differentiated from others in anthropometry, race, ethnicity, biomechanical, metabolic, and physiologic attributes. This motivates the creation of individualized human models.
3. Creating a digital human model for an individual requires a large amount of work as more individual details are included. To keep the effort tractable and affordable, one can use standard models as templates and then create individualized (instance) models from the template models via fitting, morphing, and scaling based on the

personal data. In this fashion, the individualized models will provide a representation of the person, with the level of details and medical fidelity that is sufficient for the intended applications.

4. In special applications as joint replacement and augmented reality assisted surgery, the regional models of particular parts of body or tissue groups can be created from the actual data of that person (e.g., Magnetic Resonance Imaging (MRI) data, and X-ray Computed Tomography (CT) data, etc.) so that a higher level of anatomical details and medical fidelity is attained.
5. Some human physical and biological features are not suitable to be represented by a static model and their state needs to be updated frequently. Therefore, we use data containers to store and manage updates of these data.
6. As an approximate representation of a real human, HDT/WDT is far from a complete digital replica of human. As digital human modeling technology advances, the modeling of human physical and psychological characteristics (e.g., cognitive, behavioral, and bio-physics models) will become technically feasible. The structure of our HDT/WDT is open, allowing new human models to be integrated in the future.

Concept of WDT

The Warfighter digital twin is a human digital twin created for individual Warfighters which, for a particular application as a group, share common environments, goals, needs, and requirements. As shown in Figure 1, WDT comprises individualized and unified human models combined with personal data containers with data analytics. We incorporate and integrate three different models:

- 3D Human body shape model with anthropometry, which provides a complete 3D surface mesh description of human body shape along with anthropometric measurements.
- Full body musculoskeletal model, which includes skeletal geometry, rigid linkage with multiple degrees of freedom to define joint kinematics, and Hill-type models of muscles and tendons. This provides a non-invasive means to study human kinematics and movement.
- Full body finite element model, which uses solid finite element meshes to describe the complete anatomical structure of the human body in terms of tissue groups.

Other models representing human behavior, lifestyle, and cognitive performance will be explored and evaluated in the future. They will be integrated into the unified framework when they become technically mature. These models, each of which describes specific human aspects, are integrated into a framework having unified model and data structures. This framework facilitates the sharing of common data and functional information exchange among model elements. These elements remain the same for every individual. The state-of-the-art standard models are used as the templates for the individualized models.

An individualized model is created from the template models via morphing and fitting that is appropriate for the individual. The personal data to be used includes the 3D body scan, motion capture data, MRI data, and X-ray data, each of which provides different levels of details of body.

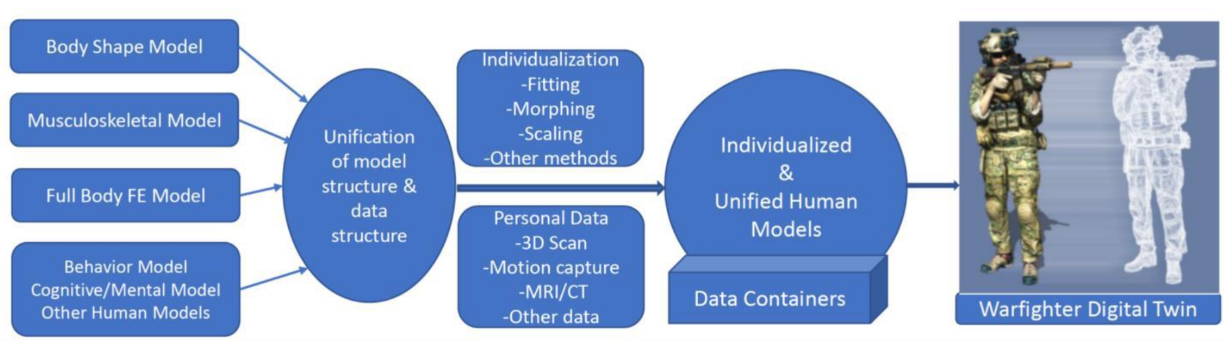


Figure 1. An overview of Warfighter Digital Twin.

Data containers are linked to wearable sensors, ambient environmental conditions, and other data sources. Data containers are used to store and manage the personal data of physical, physiological, and cognitive status, health data, activity tracking data, and medical treatment data. These data can be used to establish predictive alerts and guide people to healthier lifestyles (Bruynseels et al., 2018). Moreover, data-driven models (e.g., empirical regression models and deep neural network models) can be created from these data (Brunton and Kutz, 2019).

Features of WDT

The unique feature of WDT can be summarized as follows.

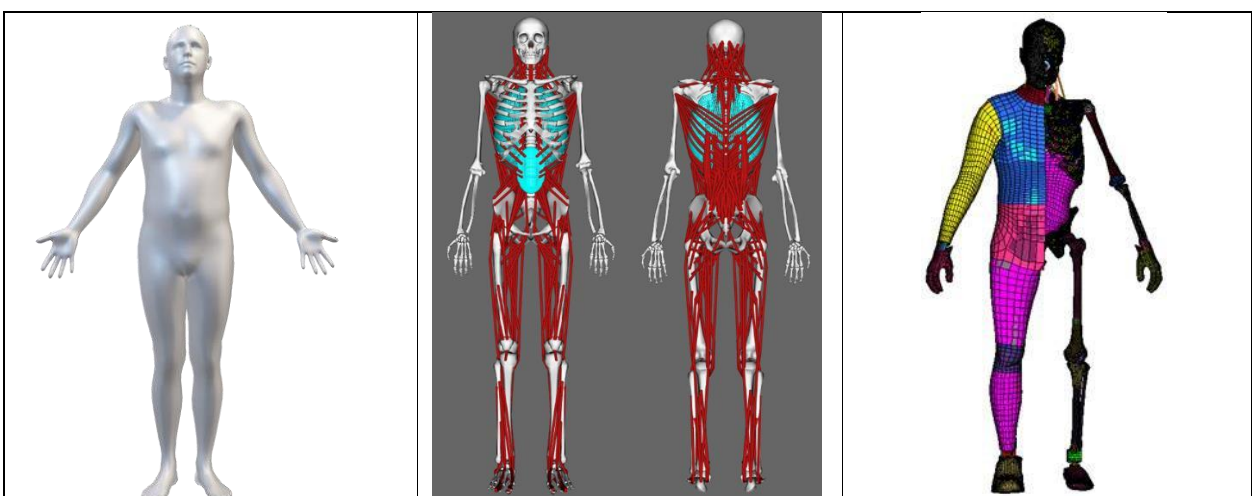
1. **Physics or first principle based:** WDT is created based on the physics and/or first principles of anthropometrics, biomechanics, physiology, biology, behavioral and cognitive sciences. Integrated with physics solvers, WDT can be used to analyze and simulate personal physical and physiological responses and status.
2. **Individualized**: WDT contains individualized human models, which are created based on the personal data, thus providing fair description of the unique features/characteristics of an individual.
3. **Unified**: Different types of human model are integrated into a unified framework with unified model structure and data structure. The unification leads to more effective and coherent representation of various features/characteristics of human and promotes synergetic utilization of different models.
4. **Quick generation:** The state-of-the-art standard models are used as the template models. The individualized models are then created from the template models by means of fitting, morphing, scaling, and other methods based on the personal data. As such, one can quickly build individualized models with tractable efforts and at the same time provide sound approximate representation of an individual.
5. **Dynamic**: Data containers are linked to wearable sensors or other data sources, so that the parameters, features, and states of WDT will be updated at different time scales which are appropriate for respective human features/characteristics.
6. **Progressive**: WDT has an open structure, allowing for new human models to be integrated when they are technically feasible.
7. **Flexible**: The level of details and bio-fidelity of the models is flexible, depending on the intended uses and data availability. Whereas the base models are intended to meet basic requirements for common applications, the refined and enhanced models can meet more stringent requirements for special applications.
8. **Affordable:** The individualized models are created from the templates via individualization. As such, the effort to build individual models becomes tractable and affordable. This is crucial to a variety of applications where cost matters.

WDT CONSTRUCTION

The process for WDT construction includes template model creation, model unification, and individualization. The methods used in these steps are described as follows.

Template Model Creation

Various methods have been developed for creating static and dynamic human shape models (Cheng and Robinette, 2009), including deriving 3D body shape models from 2D imagery via deep learning (Dibra et al, 2017). We use the parameterized human shape model developed (Figure 2(a)) as the template for human shape modeling. This template model, which can be gender-specific, is fit to the 3D body scan of an individual to generate a body shape model. The method of coherent point drift (Myronenko and Song, 2009) is used to fit the template model to the target scan surface via non-rigid registration. By this approach, point-to-point correspondence will be established between the template model and an individual model and among all individual models.



(a) Shape model | (b) Musculoskeletal model | (c) Full body FE model

Figure 2. Template models for creating individual models.

Full body musculoskeletal models are of great interest due to their ability to provide a more accurate representation of human motion. Under Dynamic Avatars with Complete Articulated Anatomy (DACAA) (Cheng et al., 2020), a small business innovative research Phase I and Phase II program sponsored by the defense health agency, a full body musculoskeletal model (Figure 2(b)) was developed by combining previously validated OpenSim (Delp et al., 2007) (https://simtk.org) models, including the full body lumber spine model (Raabe and Chaudhari, 2016), the musculoskeletal model for spinal injuries (Cazzola et al., 2017), and the upper extremity model (Saul et al., 2015). We can use this model as the template for all individual musculoskeletal models.

Full body finite element models have advanced significantly for the past decade as an important tool for assessing protection for humans exposed to dynamic events. In DACAA, we have developed a framework to convert an Individual Avatar with Complete Anatomy (IAVCA) developed by Zientara and Hoyt (2017) at the US Army Research Institute of Environmental Medicine (USARIEM) to a fully functional full body finite element model, as shown in Figure 2(c). We can use this model as the template model for all individual full body finite element models.

Human Model Unification

Human body shape, musculoskeletal system, and internal anatomical structures represent different human physical features. Yet, these are inter-related features. The unification of different types of models used to represent these features leads to a more coherent representation of various aspects of human features and characteristics. The unification promotes (a) sharing of common data; (b) exchanging/transferring information between different models; (c) synchronizing the status of different models; and (d) working together to provide more capabilities for analysis and prediction.

Contributing factors supporting model unification include: (a) Surface (skin) landmarks can be used to determine joint centers for the musculoskeletal model and bony structural features; (b) The inertial properties of body segments can be approximately determined using full body finite element model based on the body shape model; (c) An injury to or a surgery on the body can affect the body shape, anatomical structure, and musculoskeletal simultaneously; and (d) The musculoskeletal model can be used to predict a person's motion, while the full body finite element model can be used to predict the stress in a body region per frame (in an animation). The predictions from both models can then be input for a physiology engine to predict one's physiological states and vital signs (e.g., metabolic energy consumption, heart rate, breath rate, etc.).

Individualization

Human digital twin is a virtual rendition of an individual with all human characteristics. This requires all the technical means available for individualization. Individual model can be created one for one based on personal data, but a significant effort is required to build a model from scratch. Given potential applications of WDTs, if a large number of WDTs are needed, the modeling effort may become intractable. To ensure the feasibility of creating WDTs, one can create the models for an individual Warfighter via individualization which generates instance (individual) models from the template models by fitting, morphing, and scaling.

- Fitting. To create an individualized shape model, we fit a template shape model to the 3D full body scan or full body X-ray scan data of the person. This work can be done using a non-rigid registration method, such as coherent point drift (Myronenko and Song, 2009).
- Morphing: In DACAA program, a method was developed for morphing a parametric finite element model to the surface (shape) model. The process begins with statistical models of human geometry (skeleton and external body surface) that describe morphological variations within the population as functions of human parameters (age, sex, stature, and/or body mass index). Mesh morphing methods are used to rapidly morph a baseline human model into other geometries while maintaining high geometry accuracy and good mesh quality. Given a target age, sex, stature, and body mass index, the statistical human geometry models developed previously predict thousands of points that define the body posture, the size and shape of the external body surface, and ribcage and lower extremity bone geometries. The skeleton and external body shape geometries are integrated together based on the landmarks and joint locations shared in both models. Once the target geometries are developed, the baseline model is morphed to match the target geometries using a technique based on radial basis functions, as shown in Figure 3.

- Scaling: To create an individualized musculoskeletal model from its template, we will use the full body finite element model of this person to determine his joint centers and calculate linkage lengths and segment inertial properties. These parameters will be then used in OpenSim to calculate scaling factors for scaling the template model to the individual model.

The individualized models created from the templates provide an acceptable approximation to the ground truth, having a level of details and medical fidelity that meet the requirements of many applications. This approach is the primary method that we will use to create WDTs. Alternatively, to attain a higher level of details and fidelity, full body finite element model can be created from MRI or X-ray data directly, which requires specialized efforts that may exceed practical safety and financial limits. The MRI scans of the whole body are extremely rare due to motion artifacts from internal organs. MRI of large portions of anatomy are extremely expensive. The X-ray CT scans are rarely performed for ethical reasons unless there is a critical health risk that warrants the very high X-ray dose received. A full body musculoskeletal model can be created from motion capture data by registering virtual markers on the template model in OpenSim with the markers placed on the body.

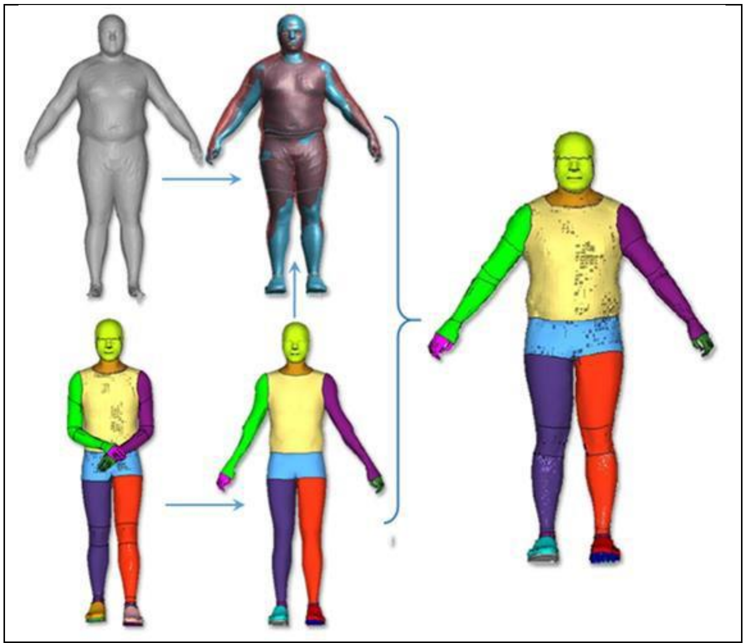


Figure 3. Morphing an FE model to a target body surface.

Data Containers with Data Driven Models

Data containers with data driven models are used for WDT to describe the human characteristics of physical components not fully parameterized or modeled. A conceptual design of WDT data containers is shown in Figure 4. Data analytics and machine learning can be applied to these data to create data driven models, which range from basic linear regression models to sophisticated DNN models (Brunton and Kutz, 2019).

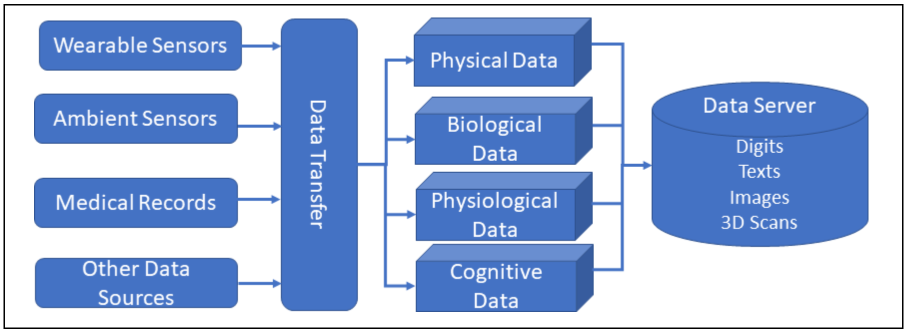


Figure 4. Data Containers for WDT.

POTENTIAL APPLICATIONS

Some potential applications of the WDT are as follows.

Personalized Military Products and Devices
These include uniform, body armor and other gears, helmet and other head mounted devices, exoskeleton and other physical assistance device or equipment. Fitting has been a major problem as up to 20% of orders are wasted due to lack of proper fit to individuals. Utilizing anthropometric and ergonomic model/data from the WDT, a particular garment or gear design can be personalized to improve or ensure fitting.

Adaptive Accommodation
For Warfighter's workspace (e.g., airplane cockpit and military vehicle interior space), the accommodation of a military population ranging from 5^{th}% female to 95^{th}% male is challenging or hard to achieve. However, using the WDT, adaptive accommodation technology can be developed, just as the adaptive seat provided by luxury cars. For instance, a standalone cockpit environment can be designed to automatically adapt to pilots from small females to large males. When a flight mission is planned, the WDT of a pilot is sent to cockpit computer to automatically adjust pilot seating according to the anthropometric and ergonomic model/data from the WDT. As such, the pilot is ready to fly once seated.

Warfighter Performance Monitoring, Analysis, and Prediction
WDT can streamline the data from wearable sensors into its data containers, thus enabling Warfighter performance monitoring. By implementing data analytics and deep learning, the time series of performance data can be analyzed to assess mission readiness and to optimize task assignment. The biomechanical and physiological characteristics represented by the WDT combined with the historical performance data can be used to predict physical and physiological performance of a Warfighter in a new mission.

Personalized Fitness and Prolonged Field Care
For Warfighter physical training, the musculoskeletal model contained in the WDT can be used to simulate training effects and to optimize training scheme. The training status and performance can be monitored and recorded using the data containers provided by the WDT. For prolonged field care, the full body 3D anatomical model contained in the WDT can provide 3D anatomical information of the wounded solider required to improve the quality of care. We have developed a concept of solution for prolonged field care using the WDT and IAVCA, as shown in Figure 5.

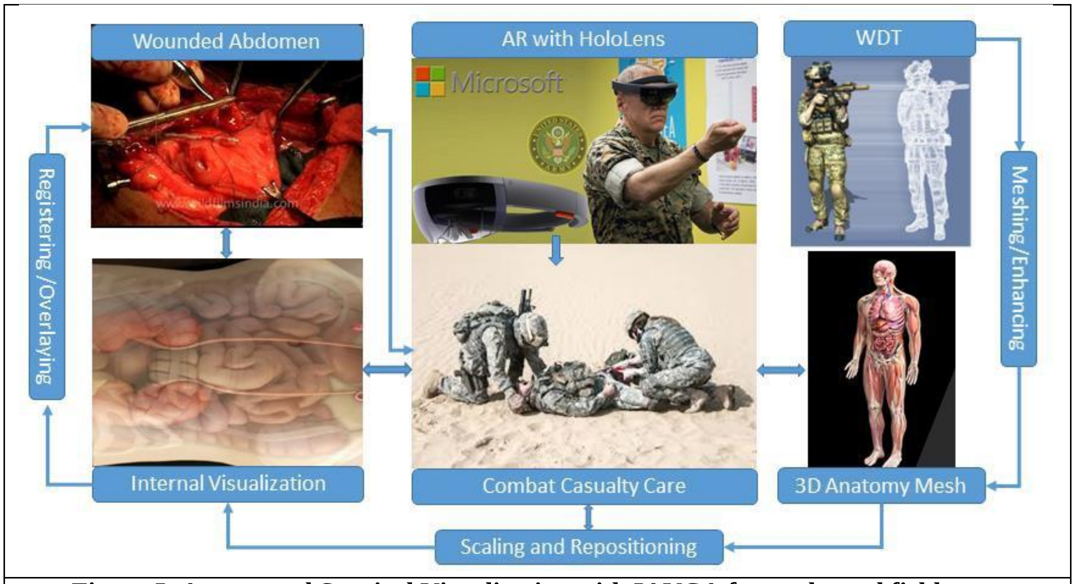


Figure 5. Augmented Surgical Visualization with IAVCA for prolonged field care.

Synthetic Training Environment and XR Technologies
Combined with an array of technologies such as gaming, cloud computing, artificial intelligence, and extended reality (XR), WDT can be used to create the first-person performance and experience where the WDT of a trainee plays a virtual role in the synthetic training environment, thus making live, virtual, and constructive training to have the increased level of fidelity and reality.

Human-Machine Teaming

In human-machine teaming, WDTs can work with digital twins of machines. With the data link to wearable sensors placed on its biological twin, a WDT can be used as a human agent to represent the human team member's physical, physiological, cognitive, and mental characteristics and state. As such, artificial intelligence and machine learning can be applied to enhance human-machine teaming.

Remote Rescue and Support

For remote rescue under harsh, restricted, or denied environments, a recue robot dispatched from an unmanned vehicle can be used to replace first responders to perform the task. By providing the WDT of the wounded solider to be rescued to the robot computer, the robot can perform its job more effectively and safely.

Smart Military Base

Military installations are the backbone of the US military forces. Smart military base is the key to tomorrow's fighting force. Warfighters are the most important assets of a military base. WDT will transform existing military systems to ecosystems, so that advanced technologies of big data, data analytics, machine learning/deep learning, and artificial intelligence can be utilized to make the US military forces faster, stronger, smarter, and more efficient.

INDIVIDUAL WARFIGHTER PHYSIOLOGICAL STATUS PREDICTION

Dismounted Warfighters often experience physiological strain close to their physiological limits in their missions. Physiological status provides the information and indication about a Warfighter's health and physiological performance. In the DACAA program, investigations were performed to develop a technology for individual Warfighter physiological status simulation and prediction, where individual Warfighter modeling and simulation illustrates a practical application of the WDT technology (Cheng et al, 2020). The apparent computer science hurdle is to accurately incorporate the virtual Warfighter's biomechanics and the effects of the environment into their physiology and metabolism, ultimately tracking the energy state of the individual. The problem was handled through a process with multiple steps: (a) Mission scenario modeling; (b) Individual Warfighter modeling; (c) Mission activity modeling; (d) Biomechanical analysis; (e) Activity energy expenditure estimation; and (f) Physiological analysis.

1. Mission Scenario Modeling. To be meaningful to and useful for military applications, the problem of individual warfighter physiological status prediction needs to be considered under real world conditions. Therefore, we have conceived a typical mission scenario, as shown in Figure 6. The basic elements of a mission scenario consist of a battlefield including the combat ground at a geolocation, military assets, and local meteorology, a team of Warfighters, mission activities, and tasks and actions performed by each Warfighter.

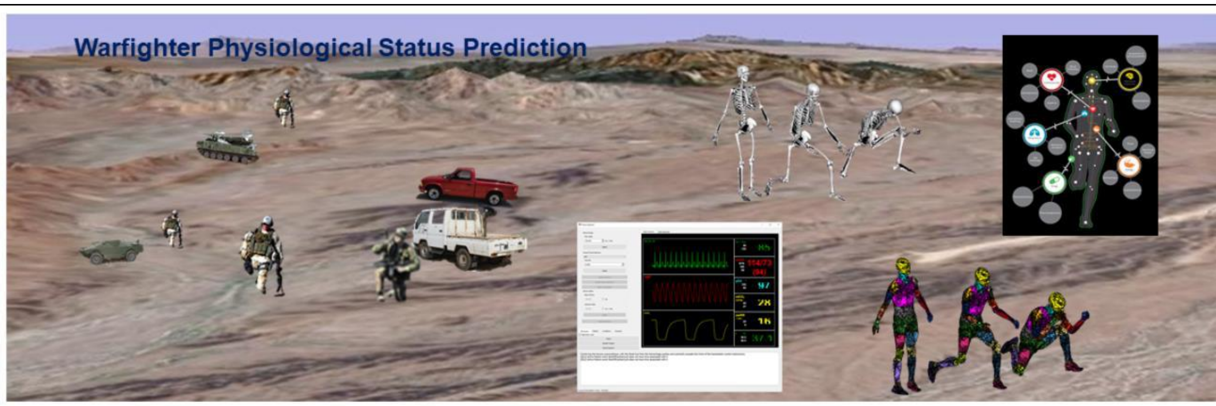


Figure 6. A mission scenario for IWPSP.

2. Individual Warfighter modeling. Within a military unit in a mission, each Warfighter may exhibit quite different physiological status even taking same tasks under same mission conditions. The difference is due to that each Warfighter has unique biomechanical and physiological characteristics. Therefore, each Warfighter needs to be modeled individually, for which the WDT technology can be used. In this study, a preliminary WDT was created to describe basic physical and physiological features.
3. Mission Activity Modeling. Mission activity modeling in this study is done via motion replication where a musculoskeletal model is animated with motion capture data. When the motion data captured from one person

are used to animate an individual musculoskeletal model representing another person, motion mapping (or retargeting) is required since two human subjects differ in their body skeleton structures.

4. Biomechanical Analysis. In a mission, a Warfighter performs various tasks. While performing a task, the body is subject to force, acceleration, and impact, therefore metabolic energy is consumed. All these affect Warfighter physiological performance and status. Biomechanical analysis can be performed to predict the Warfighter biomechanical response in a mission. The musculoskeletal model embedded in the WDT was run on OpenSim to perform inverse kinematics, whereas the full body finite element model in the WDT was run on Ls-Dyna (http://www.lstc.com) to predict human response to force and acceleration. It should be noted that while tools used for biomechanical analysis may differ from each other, their requirements of models are basically the same or similar.
5. Activity Energy Expenditure Estimation. Energy expenditure is a metabolic parameter that is fundamental to many applications involving thermal, workload, and injury risk predictions (Friedl, 2018). The rate and the time history of energy expenditure for mission tasks have direct effects on the Warfighter's physiological performance and status. The activity energy expenditure can be estimated by using a regression equation (Looney et al., 2019) or a metabolic energy expenditure model (Kim and Roberts, 2015).
6. Physiological Analysis. Several software tools are available for physiological analysis, including BioGears (https://www.biogearsengine.com/), HumMod (http://hummod.org/), VPH (https://www.vph-institute.org/), and pulse physiology engine (https://pulse.kitware.com). We choose to use pulse physiology engine as the software tool for physiological status analysis and prediction in this study, as it enables accurate and consistent physiology simulation across the medical community.

A case study was performed to test the technology and software system developed. The case is the mission of a squad marching through a rough terrain with carried body gears. From the squad, four Warfighters are selected with their anthropometric/physiological parameters listed in Table 1, which include gender (G), age, weight (Wt), height (Ht), body fat fraction (BFF), heart rate baseline (HRB), diastolic arterial pressure baseline (DAPB), systolic arterial pressure baseline (SAPB), and carried load (CL). The simulation is performed in which these Warfighters are marching on an incline with the varied grades (0, 5%, 10%) at the speed of 1.1 m/s, following the activity sequence described in Table 2 where rest implies standing, LLA-1 and LLA-2 represent low level activity at the intensity level of 0.0375 and 0.075, respectively. The metabolic energy expenditure is estimated for each Warfighter in terms of power (W), with the results given in Table 1 also. Figure 7 illustrates mission planning with WDT, and Figure 8 displays the vital signs for each Warfighter in real-time.

Table 1. Parameters for the case study.

ID	G	Age (y)	Wt(kg)	Ht (cm)	BFF	HRB (1/min)	DAPB (mmHg)	SAPB (mmHg)	C L (kg)	P (W)-rest	P(W)-0%	P(W)-5%	P(W)-10%
M01	M	22	67	175	0.21	72	73.5	114	27.24	96.48	359.3	500.3	686.2
M02	M	26	79	185	0.21	72	73.5	114	27.24	113.76	405.0	564.0	773.5
F01	F	22	55	160	0.28	72	73.5	114	27.24	79.2	313.5	436.6	598.8
F02	F	26	69	170	0.28	72	73.5	114	27.24	99.36	366.9	510.9	700.7

Table 2. Activity sequence and duration.

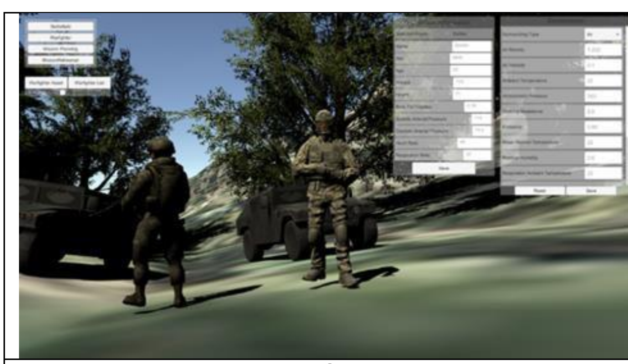


Figure 7. Battlefield modeling.

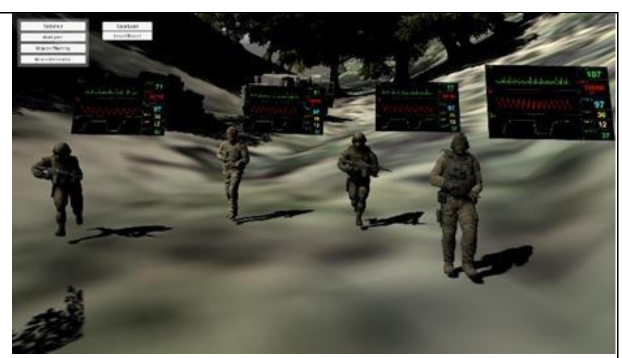


Figure 8. Real-time vital signs for each Warfighter.

DISCUSSION

Digital twins have become an enabling technology implemented by industry in recent years (Grieves 2021). We introduced the development of the WDT technology that would be applicable for the military digital engineering strategy. The human body is a complicated biological system. Any digital representation or virtual copy of human body is an approximate representation with the limited level of details and bio-fidelity. The same is true for the WDT presented in this paper. For the WDT (HDT) introduced in this paper, we use physics-based digital human models (unified and individualized) and data containers with data analytics. Based on the data collected by a WDT, various data-driven models can be derived, ranging from the simplest regression models to the most advanced deep neural network models. While many human characteristics can be effectively and rigorously represented by physics-based digital models (e.g., anthropometric and biomechanical features), others (e.g., cognitive and behavior attributes) can be more easily described by data-driven models. Moreover, human characteristics can be described by a hybrid model that integrates a physics-based model with a data-driven model (Brunton and Kutz, 2019).

A data link can be established between a WDT (HDT) and its biological counterpart to synchronize their dynamic states in real-time. This clearly differentiates a WDT (HDT) from an individualized avatar (Zientara and Hoyt, 2017) which are manipulated by user commands. The future states predicted by use of the digital twin's multisystem data can be fed back to human via the data link. If the digital twin is considered as a body, digital threads (data stream) is the 'blood' of the body. In practice, the physics-based models of the WDT (HDT) need to be updated periodically according to substantial body changes induced by injury, physical training, or other causes. The data-driven models of the WDT (HDT) can be updated more frequently, or in real-time, based on the data stream from wearable sensors/other sources. If a HDT were to accompany its biological twin for a significantly lengthy period, it would need to reflect changes during growing and aging processes.

The development of the WDT technology will be a progressive process from its current rudimentary form to a complete accurately-modeled digital twin in the future, incorporating state-of-the-art technologies that improve its level of details and bio-fidelity. Regarding the WDT described in this paper, extensive efforts are still required to complete development and to fulfill its designated functions. From general HDTs which are for average people, digital twins can be created for a specific group of people with common environments, needs, requirements, or purposes, such as patients (e.g., scoliosis patients or those with chronic back pains), Warfighters (e.g., pilots), athletes (e.g., football players), astronauts, fire fighters, first responders, etc.

The value of the WDT technology to DoD is the benefits that will bring to individual Warfighters and military systems centered around Warfighters. It has the ability to protect the health of a Warfighter and to enable predictive and retrospective physical, physiological and cognitive analyses. It has the possibility to transform existing military systems to ecosystems, so that advanced technologies of big data, data analytics, machine learning/deep learning, artificial intelligence can be applied to optimize the human-WDT synergy. The impact of the WDT technology on military enterprises and its supporting industries can be far-reaching, with numerous potential applications.

As the WDT contains personal data, the information security and privacy protection become important issues. During WDT design and development, various measures can be adopted for information security and privacy protection. During WDT utilization, strict procedures need to be implemented for the data access. Policies may need to be established at high levels for WDT management.

CONCLUSIONS

The concept of Warfighter digital twin along with an approach to construction was presented. By using individualized, unified physics-based models, WDT can effectively describe human physical and physiological characteristics. By using data containers linked to data streams, WDT can reveal personal status and performance in a timely fashion. By using data driven models, WDT can represent human cognitive, behavioral, and other performances. Integrated with physics solvers, WDT can be used to analyze and predict human physical and physiological status under force, acceleration, and other extreme conditions. Integrated with wearable sensors and ambient sensors, WDT can be used to enhance and expand Warfighter performance monitoring and assessment. There are various potential uses of WDT in the military integrated digital environments. As valuable assets of military ecosystems, WDTs can work with advanced digital technologies including big data, data analytics, deep learning, and artificial intelligence to protect, enable, and empower individual Warfighters.

DISCLAIMER

This work was partly supported by the US Army Medical Research and Materiel Command under Contract Number W81XWH18C0102. The views, opinions and/or findings contained in this report are those of the authors and should not be construed as an official Department of the Army position, policy, or decision unless so designated by other documentation.

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