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Developing an Exoskeleton Test Plan for the TALOS Program

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Abstract: As America's global adversaries increase their capabilities on the battlefield, US military forces must enhance warfighter's survivability, lethality, and mobility. These needs can be met by augmenting warfighters with additional equipment. The increased use of equipment, however, creates an additional need for an exoskeleton that can support the added equipment, while also augmenting the warfighter's mobility. Traditionally, exoskeletons have had acceptance issues related to poor operational mobility. USSOCOM is building the Tactical Assault Light Operator Suit (TALOS) as the next generation of these armored exoskeletons. This paper explains the methodology for developing a test plan to ensure adequate mobility for the warfighter wearing the TALOS system. Operational missions were decomposed into tasks which were further broken down into individual movements. Motion capture data was used to determine the angles and angular velocities imposed on relevant joints during these movements. This information was mapped to a set of exercises that were then compiled into a test plan, which can be used during the testing phase to ensure proper mobility for operators utilizing the system.

Keywords: Survivability, Lethality, USSOCOM, TALOS, Exoskeleton, Mobility

1. Introduction

"Several years ago during a hostage rescue operation in Afghanistan, a SOF (Special Operations Forces) warrior was killed going through the door. Afterwards, one of the young officers asked me a question I couldn't answer. He said, 'after all these years in combat, why don't we have a way to protect our operators going through the door?' With all the advance in modern technology, I know we can do better. Consequently, at SOCOM (Special Operations Command) we have established a program called … TALOS." (McRaven, 2015)

Admiral (retired) William McRaven's quote demonstrates an increased need for warfighters to be equipped with the latest technology to improve their survivability, lethality, and mobility. Thus, the Tactical Assault Light Operator Suit program was created to enhance these capabilities for operators engaged in traditional and future mission sets. The objective of TALOS is to increase warfighter survivability by providing armor protection to 100 percent of the body. This objective necessitates an implemented exoskeleton to support the weight of the armor and provide enhanced mission performance.

Historically, exoskeleton development has faced significant design challenges in that the exoskeleton hinders the operator's range of motion. This paper explains the methodology for developing a test plan to ensure adequate mobility for operators utilizing the TALOS system. To develop this test plan, missions were broken-down into tasks which were further broken-down into individual movements. Motion capture data of the individual movements were collected and analyzed to determine the relevant range of joints angles and angular velocities. The individual movement analysis information was then compared to a set of exercises in order to choose relevant exercises to compile into a test plan.

2. Historic Issues with Exoskeletons

The TALOS program is not the first to attempt human augmentation via a powered exoskeleton. There have been multiple military and commercial organizations that attempted human augmentation with varying degrees of success. Several of the exoskeletons were designed to enhance a warfighter's combat capability, similar to what TALOS is trying to accomplish, while others were built for ergonomic or medical purposes. For example, the Ekso Wearable Bionic Suit was designed to assist individuals who are not able to move their lower extremities on their own (Leslie, 2012). Similarly, the Japanese HAL-5 suit was designed to allow the user to drastically increase lifting and movement capabilities (Cyberdyne, 2015). Both suits have achieved a limited level of commercial success.

Other military programs have arisen over the years to create combat oriented suits. One such attempt is the Land Warrior Project which started in 1994 to provide soldiers advanced situational awareness and communication capabilities. The suit required a substantial amount of additional electronics which necessitated a passive exoskeleton. The exoskeleton component was abandoned because it could not provide enough mobility to be accepted by soldiers (Burch, 2001). Another military exoskeleton project is the Warrior Web Program, funded by the Defense Advanced Research Program Agency (DARPA). Warrior Web is developing a lower-body exoskeleton that decreases the total load carried by a soldier that simultaneously stabilizes injury prone areas such as the knees. The next stage of research for Warrior Web will address enhancing normal human abilities (Schechter, 2014). West Point also attempted human augmentation in the form of an exoskeleton in 2011. A Cadet Capstone team designed an exoskeleton that reduced the weight of equipment on a soldier by nearly 50 percent (The O&P EDGE, 2011).

All aforementioned efforts have faced similar complications in regards to their exoskeletons. The central problems are associated with designing and testing an exoskeleton that does not hinder the operator's mobility. Hardware, processing, and power requirements restrict the exoskeletons range of motion and degrees of freedom that each joint can have. However, unlike an exoskeleton, the human body has a vast range of motion at each joint. In order to reconcile the difference, exoskeletons must be able to perform within the range of motion that a warfighter uses in a combat situation. Therefore, it is inherently critical that appropriate test plans be developed to ensure these mobility requirements.

3. Methodology

3.1 Systems V

Figure 1 displays the systems V that outlines the systematic approach used for this project. The approach begins by developing a holistic view of the operating environment and an understanding of key mission scenarios applicable for TALOS. These mission scenarios are decomposed into individual activities that an operator does during the mission, to include: walking, running, side-stepping, and using hand-arm signals. Continuing down the V, each activity was analyzed for joint range of motion and angular velocity. These motion parameters were then mapped to different test exercises. 3D motion capture data gathered from Carnegie Melon University (CMU) was analyzed to ensure that the test exercises accurately captured the range of motion and angular velocity for the activities in the mission.

Several of the activities have a direct mapping to a test exercise. For example, very few exercises can mimic the movement associated with running. Therefore, the test exercise associated with this activity is running itself. However, the range of joint motions associated with walking are captured by that of running. Therefore, the running test exercise also captures the walking activity. With numerous activities and limited testing resources, it is necessary to develop a concise list of test exercises that capture a large range of activities. For example, a jumping jack captures the range of motion associated with hand/arm signals and side stepping. These activities and test exercises are used as a case study in this paper.

This strategy creates an additional benefit by protecting USSOCOM's operational security. The compiled list of test exercises allows exoskeleton developers to test their exoskeletons without needing to know the actual mission scenarios that for which they will be used.

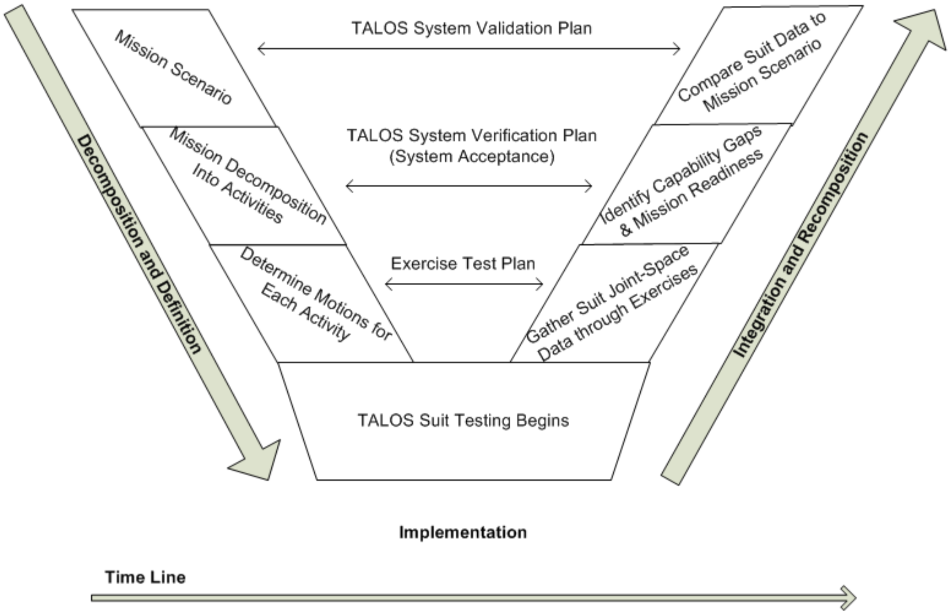

Figure 1. Systems V for decomposing mission scenario into activities and joint motions. These joint motions are then mapped to exercises consolidated into a test plan.

3.2 Data Collection

A discussion with the TALOS development team gave insight into the different operations that a SOF operator could engage in. From this discussion, an activity list was generated. A partial list of these activities included walking at 2.5 mph, walking at 3.5 mph, running at 6 mph, side-stepping, using hand-arm signals, kneeling, rolling-over, stepping up and stepping down. Each of these activities were analyzed for upper and lower body joint movements. The primary joints of concern include the ankle, knee, hips, shoulder, and elbow.

Decomposing the activities into individual joint movements relied heavily upon CMU's Motion Capture Database. The Database contains data for hundreds of motions and exercises. The CMU data collectors used a Vicon motion capture system that collected data of a subject wearing 41 markers. These markers are tracked as the wearer performs a given activity. The motion of the markers are then processed and mapped to joint angles as shown in Figure 2. Note that the shoulder marker was placed in such a way that the recorded data for the shoulder joint seems unrealistically small compared to other joints.

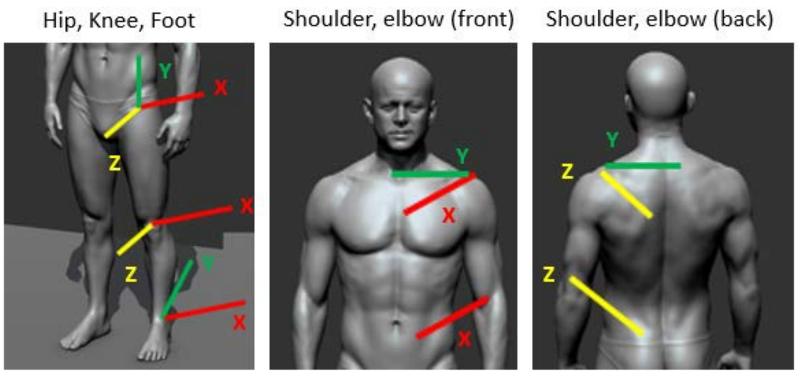

Figure 2. Joint Definitions and Coordinate System (Body Digital Image, 2016)

4. Case Study on Decomposition and Mapping to Test Exercises

A case study is presented to demonstrate the decomposition and mapping processes. The activities that are analyzed as part of this case study are side stepping and hand-arm signals, both of which are necessary activities in many operations. These activities were analyzed to determine the range of motion for each joint. These ranges were then mapped to a jumping jack to evaluate its applicability as a test exercise.

4.1 Analysis of Activities

The gathered data was statistically analyzed to determine the mean, minimum, maximum and standard deviation of values for each joint and each plane for a given movement. Additionally, the distribution of each joint was further analyzed through the use of histograms. A histogram is a graphical representation of the distribution of numerical data. They provide insight into critical data points such as the mean, mode, minimum, maximum, as well as identify outliers. Both methods are used to compare each activity to the exercises in order to validate whether the test plan exercises can be used to test operational motions.

4.1.1 Activity 1: Side-Step

Operators perform side steps when they are stepping over obstacles, or when they want to move sideways while maintaining a forward-looking posture. The data analyzed from CMU was of a person stepping repeatedly to the right-hand side. This data was processed, and a statistical analysis was performed on it to identify maximums, minimums, and means for different joint angles. The resulting analysis is shown in Table 1. As expected, the majority of the movement for the side-step occurs in the lower body. However, there is still substantial movement at the elbow as the test subject attempts to maintain his balance. Note that the shoulder movement values are rather low due to the positioning of the sensors.

The associated histograms are shown in Figure 3. The histograms for the right hip (x-plane) and the right elbow (y-plane) are extracted for visibility. The histograms can be utilized to compare operational movements to exercises, as detailed in Section 5. For example, the right hip histogram displays that the corresponding joint in the x-plane moves between -60 and -10 degrees. So, a test exercise should seek to capture that range of motions. However, at a minimum, the test exercise should capture the range of -30 and -20 degrees for this joint because the majority of movement occurs in that range.

4.1.2 Activity 2: Hand and Arm Signals

Operators use hand and arm signals throughout every mission to communicate silently with friendly units. The data analyzed from CMU was of a person directing traffic. The data was processed in the same manner as the side-stepping data. However, an additional emphasis was placed on the upper body since it was concluded that the lower body motions performed during CMU's test were irrelevant to operational hand/arm signal usage.

Table 1. Range of Motion for Joints in "Side-Step" (All Measurements in Degrees)

Lower Body		*mean*	*min*	*max*
Foot	*Right X*	-11	-39	20
	Left X	-19	-32	17
	Right Y	-2	-12	29
	Left Y	-10	-35	-2
Knee	*Right X*	19	3	70
	Left X	20	8	65
Hip	*Right X*	-26	-58	-10
	Left X	-36	-83	-21
	Right Y	-9	-20	-2
	Left Y	1	-24	8
	Right Z	-17	-25	14
	Left Z	15	-12	24

Upper Body		*mean*	*min*	*max*
Shoulder	*Right X*	-6E-16	-9E-14	6E-14
	Left X	-6E-16	-9E-14	6E-14
	Right Y	-2E-15	-2E-13	1E-13
	Left Y	-2E-15	-2E-13	1E-13
Elbow	*Right X*	-32	-40	-27
	Left X	-42	-66	-26
	Right Y	-3	-27	16
	Left Y	-8	-22	22
	Right Z	77	58	86
	Left Z	-78	-85	-65

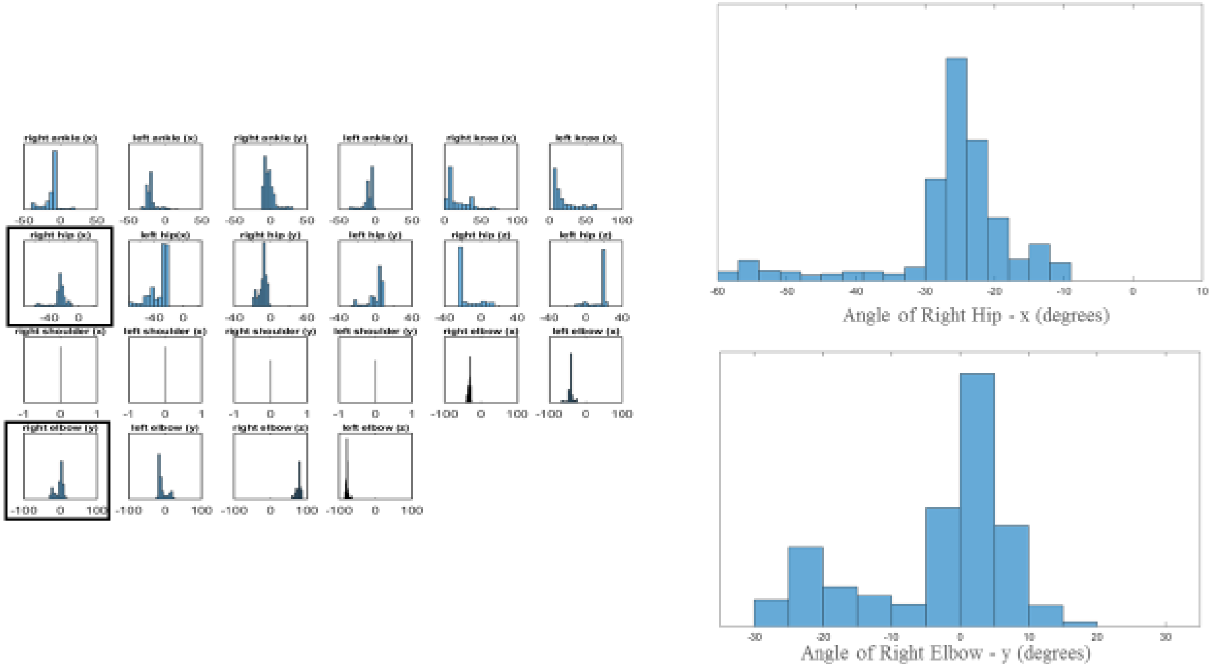

Figure 3. Joint Histograms for "Side-Step"

5. Aligning Data to Test Exercises

5.1 Methodology

After establishing the range of motions associated with each activity, the activity was aligned with a test exercise that can be compiled into an overall test plan. Several test exercises are available through the CMU Motion Capture Database; one such exercise is used for this analysis. Many of the selected exercises on the test plan are linked to FM 7-22, the Army Physical Readiness Training (PRT) program (U.S. Army, 2012). Army PRT is intended to replicate a range of tactical movements to strengthen relevant muscles.

5.2 Analysis

Using the data collected from the CMU Motion Capture Data, the ranges of motion for each operational movement as well as each testable exercise were analyzed and compared. The operational movements were then assigned to testable exercises that encompassed their ranges of motion. For example, the ranges of motion for two operational movements: "hand and arm signals", and "sidestep" can be captured in one testable exercise: "jumping jacks." As shown in Table 2, the ranges of motion for the jumping jack align with the necessary ranges of motion required to perform hand and arm signals and a sidestep. For a few joints in specific planes, the jumping jack does not fully encompass the minimum and maximums of the operational movements. In these situations, it is necessary to look at the histograms for that joint movement. The histograms ensure that the majority of the range of motion for the operational movement is covered by the test exercise. A set of sample histograms are shown in Figure 4. These histograms support the conclusion that the operational movements are adequately represented by the testable exercise. The same logic can be applied to all other operational movements as they are aligned to test exercises.

A similar analysis was performed to identify angular velocities and ensure that the jumping jack activity encompasses the range of velocities associated with the operational movements. It was found that the rapid movement associated with a jumping jack encompasses the velocities associated with the movements.

Table 2. Range of Motion for Joints in the Two Tactical Movements and the Test Exercise (All Measurements in Degrees)

		Sidestep			**Hand and arm signal**			**Jumping Jack**		
		mean	*min*	*max*	*mean*	*min*	*max*	*mean*	*min*	*max*
Foot	*Right X*	-11	-39	20	-16	-33	-1	-15	-42	20
	Left X	-19	-32	17	-17	-28	9	-19	-45	6
	Right Y	-2	-12	29	11	-7	31	6	-18	36
	Left Y	-10	-35	-2	-13	-31	27	-15	-42	14
Knee	*Right X*	19	3	70	30	19	55	50	18	140
	Left X	20	8	65	31	20	63	51	17	139
Hip	*Right X*	-26	-58	-10	-4	-17	11	-24	-102	13
	Left X	-36	-83	-21	-11	-30	7	-25	-107	12
	Right Y	-9	-20	-2	-3	-18	16	2	-27	33
	Left Y	1	-24	8	17	3	30	9	-46	39
	Right Z	-17	-25	14	-15	-28	-2	-15	-29	3
	Left Z	15	-12	24	12	0	23	12	-7	24
Elbow	*Right X*	-32	-40	-27	12	-73	89	-20	-60	45
	Left X	-42	-66	-26	39	-37	104	-15	-52	53
	Right Y	-3	-27	16	10	-48	51	1	-53	41
	Left Y	-8	-22	22	-1	-68	89	-2	-42	51
	Right Z	77	58	86	47	10	96	60	21	100
	Left Z	-78	-85	-65	-49	-125	10	-57	-96	-15

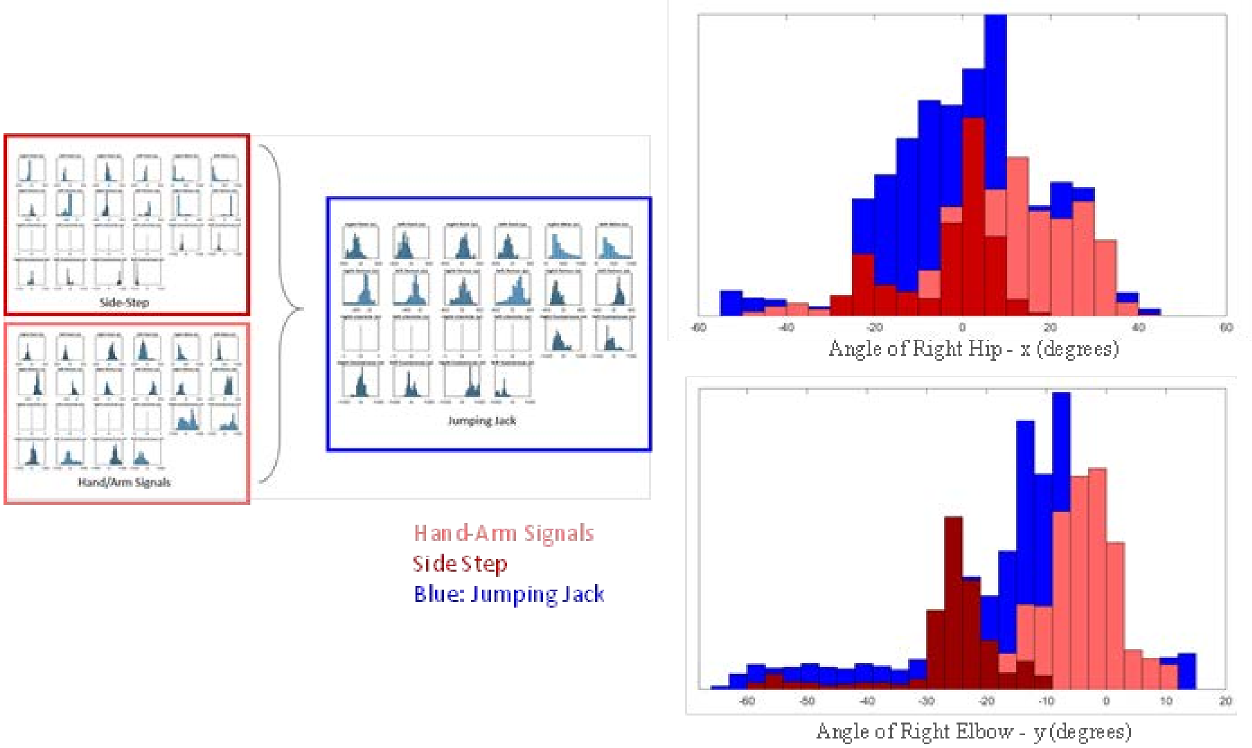

Figure 4. Histogram for Tactical Movements (Side-Step, Hand/Arm Signals) Compared to a Test Exercise (Jumping Jack)

6. Conclusions

By decomposing operational tasks into motions, two objectives were achieved. First, the operational task and its components are kept secret from the general public and possibly from potential threats. Second, the decomposition into tasks facilitates the joint by joint analysis. The joint analysis is important in that it can be used to determine which testable exercises have similar joint ranges of motion. These test exercises can then be compiled into a test plan to ensure that the operator can perform all tasks associated with the mission without being limited by the exoskeleton.

A case study is presented that maps two tactical movements, side-stepping and hand/arm signals, to performing a jumping jack. The analysis used both statistical techniques and histograms to show that a jumping-jack indeed covers a similar range of motion as side-stepping and hand/arm signals.

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