The method of measuring motion capture in wheelchairs during actual use – description of the method and model of measuring signal processing

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Abstract. The aim of the article is to verify the method of measuring motion capture in wheelchair during conditions of actual use and to formally describe how the measurement points are processed. The developed method and the measurement data processing process extract a set of parameters from the study that describe the kinematics of the human body while propelling a wheelchair. The method includes an algorithm to process data from video recorded with a sports camera to the coordinates of the marker position. For the selected marker positions, a data processing algorithm was proposed to determine universal parameters used in the assessment of the kinematics of the human body in terms of wheelchair use. The method has been verified with actual tests that analyzed the kinematics of the human body while propelling a wheelchair under various operating conditions. The proposed method of measuring motion capture involves inexpensive research equipment, offers the possibility of use in real conditions.

1. Introduction

Wheelchairs constitute a fundamental element ensuring mobility to disabled people. According to Statistics Poland’s study titled “Health status of the Polish population”, 16% of the population is disabled, including 46% of those with motor organ disabilities (acc. to the National Census of 2002). This data concerns Poland, whereas globally the number of people with motor organ disabilities is substantially higher and is increasing according to WHO reports. Due to the above, the topic of developing devices intended for rehabilitation and supporting people with disabilities to function in society is relevant and requires intensified action aimed at improving the quality of life. In case of motor function disorders, a wheelchair is the most common technical solution that compensates for a disability. The first designs of devices meeting the functional assumptions of a wheelchair were as old as 500 B.C. and have evolved to take various forms familiar today. 1885 was a special year due to the presentation of a manual wheelchair design, equipped with rims attached to the drive wheels, which is still used today. The rims served to drive the wheelchair using upper limb muscle force. This wheelchair design is currently most popular and common. Due to the increasing needs of disabled people, the strive for self-reliance and increased willingness to take active part in social life requires the use of new wheelchair designs. Currently, the most popular method of improving a classic wheelchair is to equip it with various modifications, such as the hybrid drive unit [1], multi-speed transmissions [2] and other modules that support the manual wheelchair operation with a manual traction drive [3, 4].

All these modifications require testing during the designing and construction stages. Currently, the most common tests are laboratory tests conducted on custom test benches [5, 6]. These tests allow for
determining the basic biomechanical properties, such as the human body center of gravity [7-11], resistance coefficients [12, 13], resistance forces [14] and propulsion torque [15]. However, the most advantageous are any tests conducted in real operating conditions. In reference to human-wheelchair interfaces, the measurement of the wheelchair’s kinematic parameters and muscular parameters, such as electromyography EMG, is not a problem. The greatest issue is the measurement of the human body kinematics, referred to as motion capture. The difficulty of this measurement results from the need of using specialist image recording devices and ensuring adequate object lighting conditions. Another problem is the huge size of the instrumentation intended for measuring motion capture [16, 17], which often has the form of an entire specially prepared room. Despite these limitations, many researchers make the decision to simulate a wheelchair’s real operating conditions because a motion capture measurement analysis allows for observing the direct impact of the technical object on a human. Wheelchair propulsion motion capture testing provide information about the hand motion trajectory [18-20] and on the motions of human body segments [21, 22]. Information on the trajectory of the hand movement allows to determine the angle of rotation of the wheel during the contact of the hand with the thrust and the area in which the human hand is located while driving the wheelchair. Information about the movements of individual segments of the human body allows to refer to ergonomic standards and determine whether the used propulsion system does not force unfavorable movements of the human body.

A combination of the motion capture measurement with the muscular activity measurement is an effective tool for a quantitative assessment of various design solutions. It allows you to associate any position of the upper limb with the accompanying muscular effort. In this context, it was necessary to develop a mobile interface for wheelchair propulsion motion capture measurement. Furthermore, it was advantageous to combine this instrumentation with surface electromyography (EMG) measurement instrumentation.

2. Human body kinematics during wheelchair propulsion

In the case of manual wheelchairs, the wheelchair’s linear motion is an effect of push ring repulsion [23, 24]. It must be noted that the wheelchair’s drive wheels are independent, which means that the manner of left and right push ring repulsion translates into the wheelchair’s trajectory [25]. The propelling motion consists of the propelling cycle and return cycle [19]. In the propelling cycle (Fig. 1A), the upper limbs are holding the push rings and repel them forwards. At the start of the propelling cycle, the torso is leaned against the wheelchair’s backrest, the upper limb is bent at the elbow and the hand is located on the push rings in the extreme rear position. Over the course of the cycle’s time, the upper limb is straightened out at the elbow and the torso becomes slightly leaned forwards. At the end of the propelling cycle, the hand is still located on the push rings, but now it is in the extreme forward position.

During the return cycle (Fig. 2A), the upper limbs release the push rings and come back freely to their starting position. The free movement of upper limbs features their repeated bending at the elbow without simultaneous contact between the hands and the push rings. Furthermore, the return cycle features the torso verticalization in which the entire back surface is again leaning against the wheelchair’s backrest. The return cycle ends with the hands again grabbing the push rings in the extreme rear position.

![Figure 1. Time-lapse photos illustrating the body position changes at the propelling stage (A) and return stage (B).](image-url)
Due to the fact that anthropotechnical interfaces do not feature a clear border between the propelling cycle and return cycle, it is possible to introduce an internal division of the propelling cycle. According to this division, the propelling cycle consists of the grabbing stage, effective propulsion stage and push ring release stage. During the grabbing stage, the hand balances its velocity with the push ring’s velocity and it is tightened around the push ring. Due to the stage’s specificity, the hands are slipped on the push rings. During the effective propulsion stage, the hand is constantly tightened around the push ring and the upper limb transfers the muscular force without losses. The push ring release stage is the opposite of the grabbing stage. A slip between the hand and the push ring is also observed during this stage.

![Figure 2](image.png)

Figure 2. Speed plots for a wheelchair climbing a ramp for patient 1 (a), patient 2 (b) and patient 3 (c). Where: SC – start of ramp, END – end of ramp

It is specific in manual wheelchair propulsion for the user to generate the propulsion force only during the propulsion cycle. During the return cycle, the wheelchair is only affected by the rolling resistance forces. This balance of forces affecting the wheelchair makes the wheelchair speed waveform oscillate around an arbitrary average speed. The oscillation amplitude is strictly related to the resistance force. This is especially noticeable during the wheelchair’s propulsion up a ramp (Fig. 2).

3. Measurement instrumentation

The developed measurement instrumentation included an independent module fastened to a wheelchair equipped with a load-carrying frame with a circular cross-section (Fig. 3). The image recording system consists of the GoPro HERO 7 camera (a) and an illuminating lamp (b) mounted on a boom (c) permanently combined with the wheelchair’s frame. The camera records the image at 960p and 240 fps. On the other hand, the illuminating lamp can provide illumination with the capacity of 200 to 1,000
lumens. In order to enable a motion capture analysis, the patient was equipped during the test with AruCo markers (e) positioned at body points that were subjects of the observation.

The muscle activity measurement consists of the Noraxon mini DTS surface electromyography instrument equipped with four measurement channels. The device enables measurements at the frequency of 1,500 Hz. In order to maintain the module’s mobility, it was necessary to use an EMG instrument equipped with wireless data transmission.

An advantage of this measurement module is that it can be used in any wheelchair, it has a low manufacturing cost when compared to commercial solutions and can be used in any real conditions. The module’s disadvantage is that it records the EMG signal and video image in two separate time courses. This manner of data recording slightly complicates the data processing, which must also include matching of the time units between the video image and the EMG signal.

4. Measurement methodology
The measurement methodology includes a series of preparation and measurement activities, the sequence of which should be maintained to achieve high quality measurement result (Fig. 4). The patient must firstly be prepared according to the proposed method (A1). The preparation includes equipping the patient with electrodes for surface electromyography measurement and AruCo markers which enable limb motion tracking. The next step includes the EMG signals’ normalization (B1), camera configuration through recording quality and frame quantity selection (B2). An individual calibration file for the camera must be created at the end (B3). The file is used by a software based on the OpenCV libraries and allows for identifying the AruCo markers recorded in the video image.

During the measurement module’s configuration (C1), it is necessary to adequately illuminate the recorded markers (C2) and position the camera (C3). During lighting selection, the lumen quantity must be selected experimentally to ensure a clear difference between black and white on the marker. An example of incorrect and correct lumen quantity is presented in Figure 5.
The proper measurement trial (D1) starts during the next steps and the marker (D2, F2) is marked at its beginning and end. The measurement trial (E1) is conducted after the marker is marked. Marker marking allows for synchronizing the time units of the recorded video image and the measured EMG signal (Fig. 6). The method assumed that the marker would be a touch of the index finger on one of the EMG instrument’s electrodes. This manner of measurement signals’ marking allows for observing the EMG signal’s peak, which corresponds to the time at which an electrode is placed deepest in the patient’s skin. This manner of marker marking also allows for placing the markers on two independent measurement signals.
5. Summary
The presented method stands out among other ones with the ability to simultaneously measure motion capture and electromyography in real conditions. A measurement conducted in real conditions is especially important in the case of devices operated by a human. This concerns not only rehabilitation equipment, but also other devices, the operation of which requires active operator participation [26, 27]. An advantage of the presented measurement system is the ability of research teams to reproduce it independently. An additional advantage of the system is its relatively low construction cost when compared to commercial solutions. Despite its advantages, the method and system have a disadvantage in that it is impossible to measure two signals in a single time unit. This makes it necessary to position markers and synchronize the marked signals. It is not a disadvantage that excludes the instrumentation from use, however it translates into prolonged time of processing the measured signals. The image processing method used is characterized by a low absolute error of 3% [28]. At the same time, as the previously performed studies have shown, the effects of ArUco marker velocity and size on motion capture detection and accuracy in the context of human body kinematics analysis The increase in error depends on the velocity of the marker movement.

In summary, the method is applicable in measuring the biomechanics of manual wheelchair propulsion and will be improved and modified in further research work. The apparatus in its current form, together with the developed methodology, allows to obtain data on the area of hand manipulation while driving a manual wheelchair and to link the angular position of the hand on the strings with the muscular effort. The further direction of the method's development is directed towards data processing and numerical analysis of the point cloud measured during motion capture measurement.

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