MEDICAL REHABILITATION GONIOMETRICAL SYSTEM

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Abstract. Physiological rehabilitation is applied in medical practice to restore a person's functional ability after musculoskeletal injuries. Movements in the joints are the main functional indicator of the activity of the organs of support and movement. The paper considers a resistive goniometric sensor in the form of a ball joint. Based on such a sensor, a medical rehabilitation goniometric system is developed. It includes also a data collection device (autonomous data recorder) and a portable modem. That is why the system works autonomously in real-time and transmits data over a distance. This allows the system to be mobile and control joint mobility without the direct involvement of a doctor.

Key words: Rehabilitation, joint, goniometry, sensor, system.

1. Introduction

Injuries of the musculoskeletal system are a fairly common phenomenon in medical practice. However, the war in Ukraine dramatically increased the number of people with such lesions. It is known that a whole complex of rehabilitation procedures is used in medical practice to restore functional capacity after injuries to the musculoskeletal system. Among these procedures, the so-called physiological rehabilitation occupies a prominent place.

Physiological rehabilitation includes physical exercises and natural factors in the complex process of restoring the health, physical condition, and working capacity of patients for therapeutic and preventive purposes. It flows especially with injuries to the musculoskeletal system of a person, the joints. In the rehabilitation process, it is necessary to periodically monitor the correctness of restoring the mobility of damaged joints. For this purpose, joint goniometry is used.

Goniometry of the joints is a special examination of the patient by a rehabilitation specialist to determine the amplitude of mobility in the joints. Movements in the joints are the main functional indicator of the activity of the organs of support and movement. That is why the improvement of goniometry methods and tools is an urgent task.

2. Existing methods and means of joint goniometry. Characteristics of measured values

Today, for medical use, there are several goniometers of various types [1-10] that can be used to record the degree and nature of joint damage. However, these devices and installations are not intended for continuous monitoring of the joint restoration process and their use is possible only in specialized offices. For medical practice, there is the most effective automated system [11] for assessing the functional state of the lower extremities during rehabilitation.

Such a system for assessing the functional state and restoring the mobility of the joints and feet of a person is a rather complicated installation with many units and elements from a technical point of view. To ensure effective management of the mobility process and assessment of the functional state of the lower limb, joints, and foot of a person, the system contains a control subsystem with some sensors and executive mechanisms.

First, this system is designed to assess the complex functional state of the lower limbs during rehabilitation. With the help of this system, not only mobility in the joints is evaluated, but also the strength of bending, and the speed of muscle contraction. In general, it is complex and expensive, and its use is possible only in specialized offices.

Specialized complexes such as Primus RS and Kinetec 9081 Hip CPM are used in rehabilitation practice [12-13]. These are multifunctional complexes designed for functional assessment, diagnosis, and rehabilitation of the musculoskeletal system. It has several attachments and adapters that simulate professional activities (both special and complex). They contain a touch monitor and an accessible interface, include special adapters that rotate 360° to simulate exercises at any angle; have a memory that records test and training data, a choice of resistance modes (passive, isotonic, isometric, isokinetic), and also have advanced learning opportunities: plyometrics, rhythmic stabilization, neuromuscular recovery.

The Primus RS rehabilitation device is used:

– to increase the amplitude of movements in the joints of the upper and lower limbs, muscle strength, and endurance;

– for purposeful preparation of a specific joint;

– to restore professional skills (simulation of work/production situations).

This is modern equipment that can control the rehabilitation process in the joints. However, it requires specialized staff and an office and is quite expensive. The rehabilitation simulator type Kinetec 9081 Hip CPM Machine, which is designed for passive development of the hip and knee joint, is a specialized device and provides optimal range of motion by controlling flexion, extension, adduction and abduction, and external rotation.

Application of the simulator:

– the procedure that prevents joint swelling requires early activation of the patient and his interaction in the postoperative period;

– hip and knee endoprosthesis, hip and lower leg osteosynthesis, synovectomy, and meniscectomy, quadriceps muscle release;

– hip and knee prostheses, osteotomy of the knee and hip joints, fractures of the upper end of the thigh with open reduction and internal fixation, and acetabular and distal femoral fractures.

Functional and technical characteristics:

Range of motion:

– hip – (extension – flexion – adduction / abduction): 0 – 120° – 0 – 30°;

– knee – (extension – flexion – adduction/abduction): 0 – 0°, 30°, 60°, 90° or 120° – has anatomically correct movements of the hip joint;

– the optimal volume of movements;

– shock absorption system to transfer the weight of the leg from the damaged hip joint, making the procedure more comfortable.

During rehabilitation, the joint must be constantly cooled, as low temperature prevents the formation of edema and relieves pain.

The equipment requires a stationary office, specialized personnel and is quite expensive.

The simplest device, which is now most often used in medical practice to measure joint movements, is a universal protractor or goniometer [1] (Fig. 1).

It consists of a protractor 1 with a scale up to 180°, to which two 2 or 3 arms 30-40 cm long are attached. One of the branches is movable. When measuring, the axis of the protractor must coincide with the axis of the joint, and the branches are located behind the axes of the segments united by the joint. When measuring movements in the shoulder joint, 0° is taken as the initial value when the hand is lowered and the protractor branches are closed. When measuring movements in the elbow, carpal, hip, and knee joints, 180° is taken as the starting value, and 90° in the ankle joint.

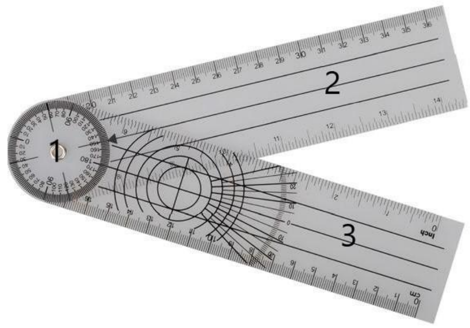

Fig. 1. Universal goniometer:
1 is the protractor; 2 and 3 are the protractor arms

Joint movements are measured according to the international SFTR method (neutral – 0°, S – movements in the sagittal plane, F – in the frontal plane, T – movements in the transverse plane, R – rotational movements). These measurements are recorded in degrees.

Physiological movements in the shoulder joint are flexion up to 90°, extension – up to 45°, and abduction – up to 90°, further abduction occurs already with the participation of the scapula and is possible up to 180°. Rotational movements are possible in the shoulder joint. Movements in the elbow joint are possible within the following limits: flexion – up to 150°, extension – up to 0°. In the radiocarpal joint, movements are performed within 60-90° of palmar flexion and 60-80° of palmar flexion. Lateral movements of the hand are also determined – radial abduction in the range of 25-30° and ulnar – in the range of 30-40°.

However, such measurements are carried out in the rehabilitation room with the participation of a doctor and are generally time-consuming, and require skills.

The most appropriate, for creating an automated goniometric system, is a goniometric sensor [13], made in the form of a spherical joint consisting of a spherical core and a spherical clip. Here. the spherical core is made in the form of a hollow sphere, partly of ferromagnetic, and partly of non-magnetic material, and two pairs of inductance coils are placed in a spherical holder, equidistant to the spherical surface, in two mutually perpendicular planes.

When the spherical core rotates relative to the spherical holder, the inductance of the coils changes and one pair of coils registers the angular movement of the spherical core in one plane; the 2nd pair of coils – in the other, resulting in two output signals. However, the production of a spherical core in the form of a hollow sphere partly from ferromagnetic and partly from non-magnetic material is technologically complex. Therefore, such a sensor is massive and expensive to manufacture. In addition, the registration and processing of exactly two output signals require quite complex metrological support.

3. Disadvantages

Existing goniometers or goniometric systems are inherent in several disadvantages that limit their use. First, this hardware complexity, expensiveness, and functioning are possible only in specialized offices with the participation of qualified personnel. The mentioned devices and systems are stationary, so cannot be permanent with the patient and provide him the opportunity to be under supervision while being outside a medical institution. Second, the universal protractor is simple in design and cheap, but it is not mobile and also requires the participation of qualified personnel.

4. Goal

The purpose of the work is to develop a mobile medical rehabilitation goniometric system for monitoring the functional state of joints during rehabilitation.

5. Development of a goniometric sensor

To realize the goal, a goniometric sensor is developed in the form of a spherical joint (Fig. 2).

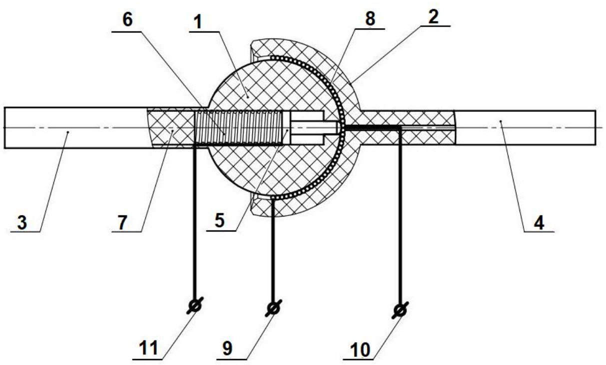

Fig. 2. Goniometric sensor: 1 is the spherical core; 2 is the spherical clamp; 3,4 are the states (branches); 5 is the contactor; 6 is the spring; 7 is the locker; 8 is the wire spiral; 9, and 10 are the leads of the spiral; 11 is the outlet of the contactor

By design, the sensor is similar to a joint and consists of a spherical core 1 and a spherical holder 2, which are made together with holders 3 and 4. A wire spiral 8 is tightly laid along the spherical holder. In the middle of the spherical core 1 and holder 3 there is a channel in which the contactor is located 5. This element is pressed by spring 6 to the wire spiral, and retainer 7 keeps spring 6 compressed. The spherical core and the spherical clip with holders are made of non-conductive material. The supply voltage is applied to terminals 9 and 10 of coil 8, and the output signal is an electrical resistance removed between terminal 9 and terminal 11, which is connected to the contactor.

With the help of holders, the sensor is attached to objects whose relative angular displacement must be measured. During the movement of these objects, the spherical core slides in the spherical holder, and the contactor touches the spiral at one point or another. The coordinate of the point of contact of the contactor with the spiral is described by two angles in the spherical system, which can be imaginatively tied to the spherical sensor bracket. Each point of the wire spiral uniquely determines the amount of electrical resistance that is removed between the contactor terminal and the spiral terminal.

Based on one value of the output signal – the value of electrical resistance, we get the values of two input signals – the angles of the mutual spatial arrangement of objects. This principle of operation of the sensor ensures the simplicity of the measurement transformation, which increases the accuracy of the measurement and the reliability of the operation.

To obtain the static characteristics of the sensor, project a spherical wire spiral 8 on the horizontal and frontal (vertical) planes (Fig. 3 and 4).

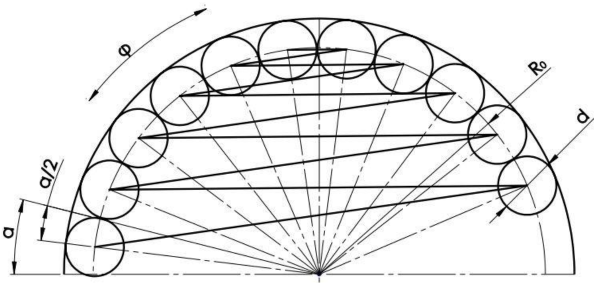

Fig. 3. Projection of a spherical spiral on the frontal plane

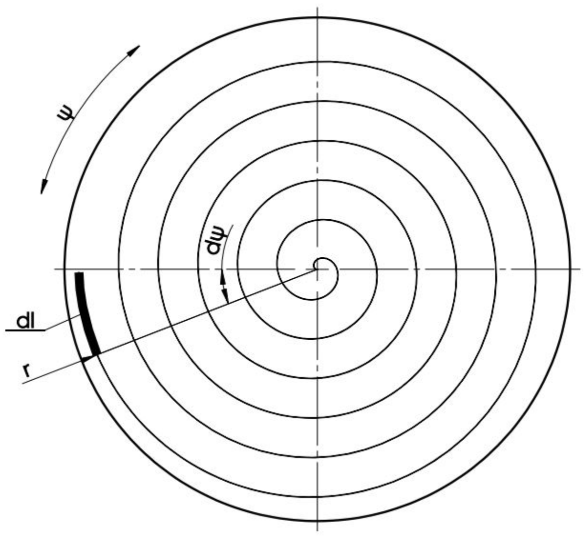

Fig. 4. Projection of a spherical spiral on a horizontal plane

Let the contactor 5 move along the turns of the spiral 8. Then in the frontal plane, there is a movement along the angle φ, and in the horizontal plane, there is a movement of the holder 3 along the angle ψ. It can be seen from Fig. 3-4 that when rotating through the angle φ, we have a dependence between it and the angle ψ:

$$\varphi = \frac{\alpha}{360^o}\psi , \quad (1)$$

where $\alpha = 2\arcsin\frac{d}{2R_0}$ is the angular pitch of the wire spiral 8; d-diameter of the wire of the spiral 8, which is lined on the surface of the clip 2; R0 is the radius of the centers of spiral turns 8. In turn, the running radius r: $r = R_0 \cos\varphi$ .Then the element dl of the spiral projection 8 is equal to $dl = rd\psi$. Therefore, the length of the entire spiral 8 is:

$$l = \int_0^\psi rd\psi = \int_0^\psi R_0 \cos\frac{\alpha}{360^o}\psi d\psi = \frac{R_0 360^o}{\alpha}\sin\frac{\alpha}{360^o}\psi \Big|_0^\psi . \quad (2)$$

The upper limit of the angle ψ (the number of complete revolutions of the holder 3) is:

$$\psi = \frac{\pi R_0}{2d}2\pi = \pi^2\frac{R_0}{d} . \quad (3)$$

When reaching the top of spiral 8, the angle ψ is maximum or φ=90, so the full length of the spiral is determined as:

$$L = \frac{R_0 360}{\alpha}\sin 90 = \frac{R_0 360}{\alpha} . \quad (4)$$

The resistance of the spiral section from the beginning to the point of contact between the spiral and the contactor

$$R = \rho\frac{l}{S} , \quad (5)$$

where ρ is the specific resistance of the spiral material; the S-area of the cross-section of the spiral. From (5), we obtain $l = \frac{R \times S}{\rho}\leq$. Therefore,

$$\frac{R \times S}{\rho} = \frac{R_0 360}{\alpha}\sin\frac{\alpha}{360}\psi \quad (6)$$

Considering (1) and (6), we come to:

$$\left.\begin{aligned} \psi &= \frac{360}{\alpha}\arcsin\frac{S\alpha}{360\rho R_0}R \\ \varphi &= \arcsin\frac{S\alpha}{360\rho R_0}R \end{aligned}\right\} \quad (7)$$

The system of equations (7) is a two-parameter static characteristic of the developed sensor. Using it, we calculate the value of the input signals – angles, which describe the mutual angular movement in the joint, based on the value of the electrical resistance R of the spiral section.

5.1. Characteristics of the goniometric sensor

The developed goniometric sensor of the resistive type in the form of a ball joint has a range of measuring angles of ±70° in each plane, which meets the needs of a wide range of medical and rehabilitation tasks. The value of the angles of mobility of the joint in two planes is determined by one measured value of the electrical resistance of the wire spiral of the developed sensor, which is a significant advantage in comparison with analogs. However, before starting work, the sensor must be set to zero. The error in measuring joint mobility angles is ±1°.

5.2. Technological features of the sensor

Elements of the ball joint of the sensor are made of a non-conductive material, such as fluoroplastic or ebonite. The wire spiral is fulfilled of a material that should have high resistance, corrosion resistance, mechanical strength, and ductility, and should not be expensive. Constantan is such a material. It is an alloy of copper and nickel and has the following properties: stability of the temperature coefficient of expansion up to 200 °C, temperature coefficient of resistance at 20°C: 0.00003 / °C, high oxidation resistance, and sufficient mechanical strength. The wire spiral is fixed on the ball joint holder using C52-1 glue, which is characterized by minimal changes in temperature and elastic properties over time, and also ensures a strong bond between constantan and plastics.

6. The structure of the medical rehabilitation goniometric system

To implement the mobility and autonomy of the joint rehabilitation control process, a system is proposed, the generalized structural diagram of which is shown in Fig. 5.

The principle of operation of the system is as follows. The sensor transforms the measured physical value into a signal (usually electrical), which enters the input of the data collection and processing device. This device includes a unified converter. At its output, we receive an analog unified signal, which, in turn, enters the input of the calculation unit. From this device, the signal is processed – in fact, the value of the angles in the joint elements is sent to the modem. The latter serves to convert an analog signal into a signal that is convenient for transmission and reception at the other end of the communication channel – the doctor's computer.

Depending on the modem of the system, you apply the wire, radio, or GSM communication lines transmitting the signal. Visualization of the developed medical rehabilitation system is presented in Fig. 6.

The data collection device with an autonomous recorder receives a signal from the goniometric sensor. The latter is filtered from noise and amplified, then amplified to such a level that the maximum corresponds to the input range of the ADC of the data acquisition device. For the convenience of visualization of measurement results, the output signal is linearized. This is done by software with the help of an RS-232 interface and Alcatel LINKKEY IK 41 LTE USB (IK41VE) modem. It provides a high-speed Plug & Play connection and connects external LTE antennas for high-speed communication even in places with a low signal level of the mobile network.

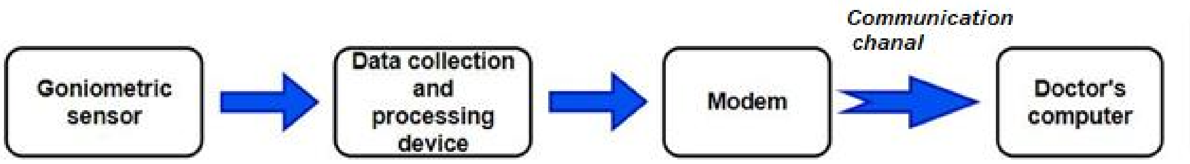

Fig. 5. Generalized structural diagram of the goniometric system

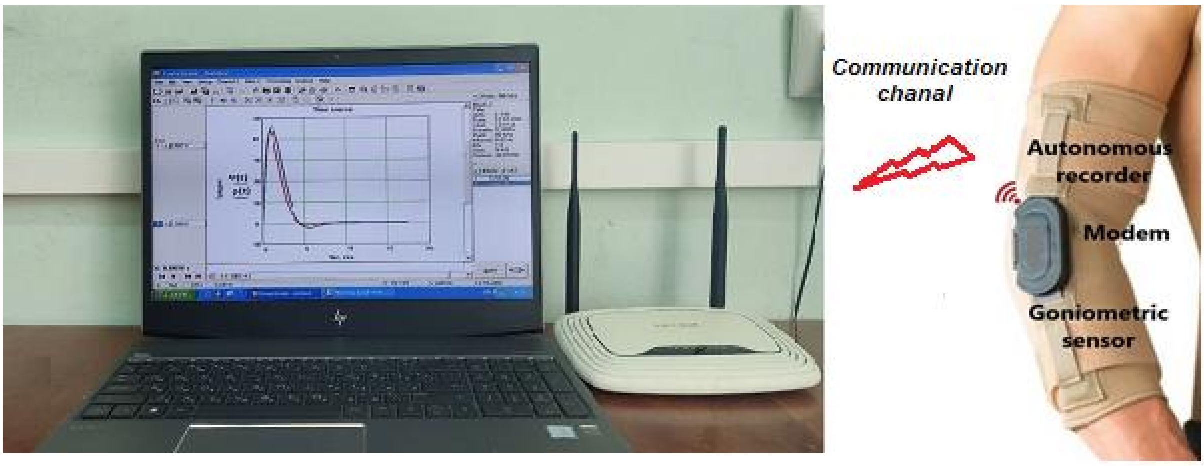

Fig. 6. Medical rehabilitation goniometric system

7. Conclusion

The developed design of the goniometric sensor and the proposed hardware structure of the medical rehabilitation system is projected and fulfilled autonomously and mobile. The last quality allows the patient to be outside the medical facility, and the medical worker can permanently control the mobility of the damaged joint.

8. Acknowledgments

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9. Conflict of interest

There were no financial, organizational, or other possible conflicts during the performance of the work.

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