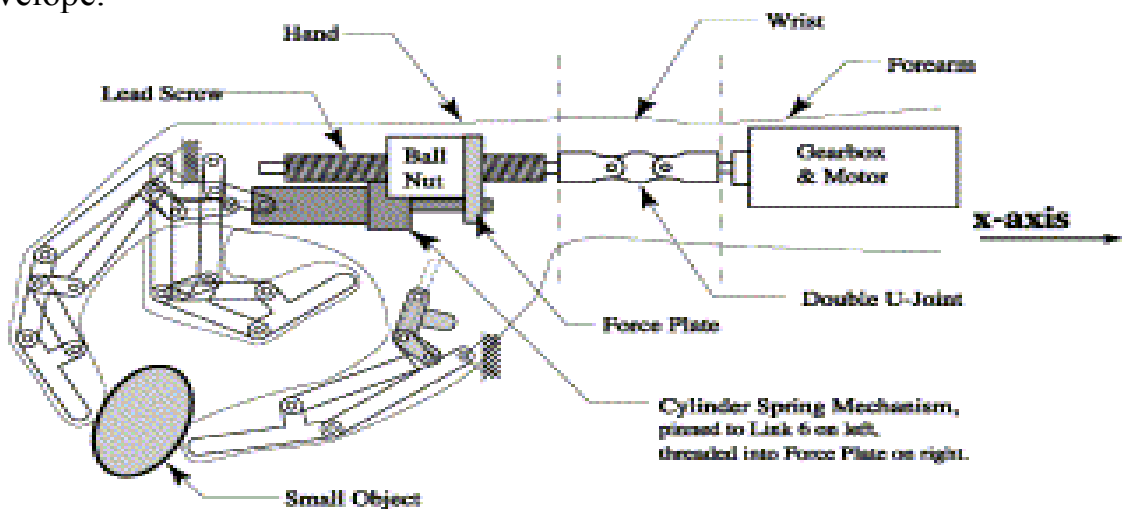


ROBOTICS IN MEDICAL CARE

Zayarny V.P., Anushika Jayasooriya
 Belarusian national technical university
 Minsk, Belarus

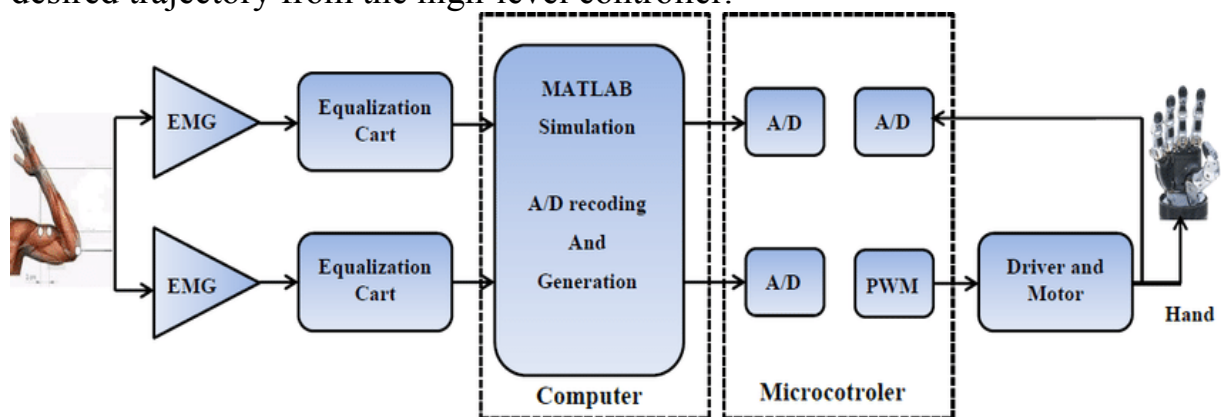
The operation of modern my electric hand prosthesis is governed by a mathematical pipeline that translates biological signals into controlled mechanical force. This work formalizes the key transformations from electromyography (EMG) signal acquisition to adaptive grip force control, presenting the governing equations and their practical significance. The raw my electric signal $m(t)$ is a stochastic, zero-mean time series recorded via surface electrodes. To extract usable information, it first undergoes band pass filtering (typically 20–500 Hz) to remove motion artifact and DC offset, followed by full-wave rectification and smoothing via a low-pass filter to produce the signal envelope.



Picture 1. Structural diagram prosthetic hand.

The dominant technology in commercial and research prostheses are the DC brushless motor. These motors are preferred for their high torque-to-weight ratio, reliability, and efficient power use. A single prosthetic hand typically contains multiple independent motors often five or six dedicated to specific movements: one for the thumb's opposition, one for the index finger, one for the middle finger, and a shared motor for the ring and little fingers, with an additional motor for thumb rotation or wrist movement. This under-actuated design (using fewer motors than degrees of freedom) is a clever compromise, reducing weight and complexity while still enabling a wide range of pre-programmed grip patterns, such as key pinch, palmer grasp, and tool hold. The motors are exceptionally small, often no larger than a pencil eraser, yet they can generate a fingertip pinch force of 30 to 150 Newton's enough to firmly hold a bag of groceries or delicately grasp a grape. For a more biometric approach, research is advancing alternative actuator technologies. Shape Memory Alloy

(SMA) wires act like artificial muscle fibers: when an electrical current heats the alloy, it contracts, pulling a tendon to flex a finger. While quieter and more direct in its imitation of muscle contraction, SMA technology struggles with slower response times and higher energy consumption due to the heating and cooling cycles. Another promising area is pneumatic or hydraulic artificial muscles (PAMs, which are soft, inflatable actuators that contract when pressurized. These offer excellent compliance and a natural "softness" in interaction, making them ideal for applications where safety and adaptability are paramount, such as in prosthetics designed for children or for tasks involving fragile objects. Integrated sensors, such as encoders and torque sensors, constantly measure the motor's actual position, velocity, and output force. This data is fed back to the prosthesis's microcontroller, which compares it to the desired trajectory from the high-level controller.



Picture 2. System of control prosthetic hand

Mathematical models for hand prostheses involve kinematic, dynamic, and control equations, primarily utilizing Denavit-Hartenberg (D-H) parameters for motion, Euler-Lagrange for dynamics, and linear static analysis for finger force calculation. Key equations determine finger phalanx lengths, joint transformation matrices, and motor torque. Kinematic Modeling (D-H Method): Used to determine the position of the fingertip based on joint angles. The Homogenous Transformation Matrix Finger Link Length Motor Torque Equation Unlike current prosthetics that are either purely cosmetic or offer basic motor control, our solution aims to restore the sensation of touch and proprioception. The breakthrough is two-fold Tactile Sensor Skin will implement a flexible sensor array that not only detects pressure but also distinguishes between textures and temperatures. On-Device Learning Instead of relying on cloud computing (which has latency), we will use a microcontroller capable of "on-device" incremental learning. This allows the prosthesis to adapt to the user's unique micro-movements and predict grip types in real-time without external processing, making the control feel intuitive and instantaneous.

DC coreless motors are used in bionic hands because they are lightweight, durable, small, and have a high output/volume ratio. In addition, they are very

energy efficient, allowing the prosthetic to be used for several days between charges.

Table 1. List of components of a prosthetic hand

Component	Example	Function
Input (brain)	SEMG Electrodes, IMES	Captures intention
Processor	Microcontroller (ARM, Arduino)	Interprets signal & commands motors
Actuator(motor)	DC Servo, Linear Actuator	Moves fingers (flexion/extension)
Transmission	Tendons (Dyneema), Gears	Transfers power to joints
Sensor(feedback)	FSR, IMES, Encoders	Detects pressure, slip, position
Output(sensory)	Vibrotactile Motor	Provides feeling

While modernized hand prosthetics elsewhere integrate whisper-quiet motors and intuitive my electric sensors for a natural, easy grip, Belarusian patients face a starkly different reality where such technology remains effectively absent. The national healthcare discourse, focused on joint replacements and spinal systems, makes no mention of advanced upper-limb bionics instead, the prosthetic sector is explicitly restrained by a "limited availability of skilled prosthetics" and the total "lack of reimbursement policies" leaving cutting-edge devices financially and logistically out of reach .While neighboring countries advance, Belarus exports expertise in rehabilitation centre layouts ,yet within its borders, amputees are left waiting not for an upgrade, but for the very infrastructure that would make a modern, functional hand anything other than a foreign luxury.

References

1. Yang H., Tao Z., Yang J., Ma W., Zhang H., Xu M., Wu M., Sun S., Jin H., Li W., Wang L., Zhang S. (2025). A lightweight prosthetic hand with 19-DOF dexterity and human-level functions. *Nature Communications*,16(1), 955. <https://doi.org/10.1038/s41467-024-54837-9>.
2. Kalita A. J., Kalita Z., Kakoty N. M., (2025). Clinical evaluation of prosthetic hand: A systematic review on existing methods, limitations and future directions. *Medical Engineering & Physics*, 146, 104432. [<https://doi.org/10.1016/j.medengphy.2025.104432>] (<https://doi.org/10.1016/j.medengphy.2025.104432>).