EDUCATION AND SCIENCE MINISTRY OF UKRAINE
NATIONAL AVIATION UNIVERSITY
DEPARTMENT OF COMPUTER INTEGRATED COMPLEXES

ADMIT TO DEFENSE
Head of department
Viktor M. Sineglazov
“____” ______________ 2020

MASTER’S THESIS

(EXPLANATORY NOTE)

GRADUATE OF EDUCATION AND QUALIFICATION LEVEL
“MASTER”

THEME: BIONIC PROTHESIS CONTROL SYSTEM

Executor: **Avagian A.V.**

Supervisor **Ph.D., Senior Lecturer Pantyeyev R.L.**

Advisor on environmental protection: **Ph.D., Associate Professor Frolov V.F.**

Advisor on labor protection: **Ph.D., Associate Professor Konovalova O. V.**

Norms inspector: **Ph.D., Associate Professor Tupitsyn M. F.**

Kyiv 2020

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ
КАФЕДРА КОМП'ЮТЕРНО-ІНТЕГРОВАНИХ КОМПЛЕКСІВ

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач кафедри
В.М. Синєглазов
"_____"____________2020 р.

ДИПЛОМНА РОБОТА

(ПОЯСНЮВАЛЬНА ЗАПИСКА)

ВИПУСКНИКА ОСВІТНЬО-КВАЛІФІКАЦІЙНОГО РІВНЯ "МАГІСТР"

Тема: СИСТЕМА КЕРУВАННЯ БІОНІЧНИМ ПРОТЕЗОМ

Виконавець: **Авагян А.В.**

Керівник: **к.т.н., старший викладач Пантєєв Р.Л.**

Консультант з екологічної безпеки: **к.т.н., доцент Фролов В.Ф.**

Консультант з охорони праці: **к.б.н., доцент Коновалова О.В.**

Нормоконтролер: **к.т.н, доцент Тупіцин М.Ф.**

Київ 2020

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Факультет аеронавігації, електроніки та телекомунікацій

Кафедра авіаційних комп'ютерно - інтегрованих комплексів

Освітній ступінь магістр

Напрям 15 – Автоматизація та приладобудування

ЗАТВЕРДЖУЮ

Завідувач кафедри

Синєглазов В.М.

" ____ " __________2020 р.

ЗАВДАННЯ
на виконання дипломної роботи студента
Авагяна Арутюна Вардгесовича

1. Тема роботи: «Система керування біонічним протезом»

2. Термін виконання роботи: з 01.09.2020р. до 10.12.2020р.

3. Вихідні дані до проекту (роботи): розглянути існуючі біонічні протези рук і використати їх в повній мірі.

4. Зміст пояснювальної записки (перелік питань, що підлягають розробці):

1. Аналіз існуючих моделей протезів. 2. Основні способи використання 3D моделювання і печаті для вирішення ряду проблем при виготовленні протезу. 3. Опис системи управління положенням виконавчого органу. 4. Перелік основних компонентів для біонічного протезу. 5. Обробка сигналу керування з м'язевого сенсора.

5. Перелік обов'язкового графічного матеріалу:

1. Схема системи управління положенням. 2. Структурна схема системи управління положенням. 3. Структура цифрової системи регулювання положенням. 4. Графік вихідного сигналу з датчика електроміографії. 5. Графік налаштованого сигналу керування.

6. Календарний план-графік

№ п/п	Завдання	Термін виконання	Відмітка про виконання
1	Підбір літератури	01.09.2020-11.09.2020	виконано
2	Аналіз існуючих біонічних протезів	11.09.2020-22.09.2020	виконано
3	Модернізація пристрою	22.09.2020-03.10.2020	виконано
4	Дослідження системи управління положенням сервопривода	03.10.2020-14.10.2020	виконано
5	Розробка програмного забезпечення для контролера	14.10.2020-25.10.2020	виконано
6	Поєднання всіх компонентів в єдиний пристрій	25.10.2020-05.11.2020	виконано
7	Формування висновків щодо виконаної роботи	05.11.2020-16.11.2020	виконано
8	Оформлення пояснювальної записки	16.11.2020-27.11.2020	виконано
9	Створення презентації	27.11.2020-10.12.2020	виконано

7. Консультанти зі спеціальних розділів

Розділ	Консультант (посада, П. І. Б.)	Дата, підпис	
		Завдання видав	Завдання прийняв
Охорона праці	к.т.н., доцент, Коновалова О.В,		
Охорона навколишнього середовища	к.т.н., доцент, Фролов В.Ф.		

8. Дата видачі завдання ____

Керівник: старший викладач________________________________ Пантєєв Р.Л.

(підпис)

Завдання прийняв до виконання ______________________________ Авагян А.В.

(підпис)

NATIONAL AVIATION UNIVERSITY

Faculty of aeronavigation, electronics and telecommunications

Department of Aviation Computer Integrated Complexes

Educational level master

Field of study: 15 “Automation and Instrumentation"

APPROVED BY

Head of department

Victor M. Sineglazov

“_____”________________ 2020

Graduate Student’s Diploma Thesis Assignment

Avagian Arutiun Vardhesovich

1. The thesis title: "Bionic prothesis control system"

2.The thesis to be completed between: from 01.09.2020 to 10.12.2020

3. Output data for the thesis: consider the existing bone dentures of the hands and use them to the fullest.

4. The content of the explanatory note (the list of problems to be considered): 1. Analysis of existing models of dentures. 2. The main methods of using 3D modeling and printing to solve a number of problems in the manufacture of prostheses. 3. Description of the management system of the executive body. 4. List of basic components for bionic prosthesis. 5. Processing of the signal from the muscle sensor.

5. List of compulsory graphic material: 1. Scheme of position management system. 2. Structural diagram of the control system of the situation. 3. The structure of the digital position regulation system. 4. Schedule of the output signal from the electromyographic sensor. 5. Schedule of the configured control signal.

6. Planned schedule:

№	Task	Execution term	Execution mark
1	Selection of literature	01.09.2020-11.09.2020	done
2	Analysis of existing bionic prosthetics	11.09.2020-22.09.2020	done
3	Device upgrade	22.09.2020-03.10.2020	done
4	Investigation of the control system of the servo actuator	03.10.2020-14.10.2020	done
5	Software development for controller	14.10.2020-25.10.2020	done
6	Combining all components into a single device	25.10.2020-05.11.2020	done
7	Formation of conclusions on the performed work	05.11.2020-16.11.2020	done
8	Making an explanatory note	16.11.2020-27.11.2020	done
9	Create a presentation	27.11.2020-10.12.2020	done

7. Special chapters' advisors

Chapter	Advisor (position, name)	Date, signature	
		Assignment issue date	Assignment accepted
Labor protection	Ph.D, Associate Professor, Konovalova O. V.		
Environmental protection	Ph.D, Associate Professor, Frolov V.F.		

8. Date of task receiving: ____

Diploma thesis supervisor _______________ Pantyeyev R.L.
(signature)

Issued task accepted _________________ Avagian A.V.
(signature)

РЕФЕРАТ

Пояснювальна записка до дипломної роботи «Система керування біонічним протезом»: 122 с., рис. 54, 21 літературних джерела.

Об’єкт дослідження: система керування біонічним протезом.

Мета роботи: розробка дешевого прототипу біонічного протезу руки.

Методи дослідження: виготовлення прототипу, прведення експериментів, аналіз результатів.

3D ДРУК, СЕРВО ДВИГУНИ, ФІЛЬТРАЦІЯ СИГНАЛУ, АЛГОРИТМ РОБОТИ, МУСКУЛЬНИЙ СЕНСОР, МІКРОКОНТРОЛЕР.

ABSTRACT

Explanatory note to the thesis "Bionic prosthesis control system": 122 p., 54 figures, 21 literary resources.

The object of research: bionic prosthesis control system.

The purpose of the work: development of a cheap prototype of a bionic hand prosthesis.

Methods of research: prototyping, conducting experiments, analysis of results.

3D PRINT, SERVO MOTORS, SIGNAL FILTRATION, WORK ALGORITHM, MUSCLE SENSOR, MICROCONTROLLER.

Content

List of abbreviations

EMG – electromyography

MCU – microcontroller

CAD - computer-aided design

CS - control system

SR - selsin receiver

EA - executive agency

ACC - angle code converter

CD - computing device

PCS - position control system

RC - rotation control

dc - digital computer

INTRODUCTION

Prosthetics is a recovery of the got out of shape and functions of separate bodies or parts of a body.

Prosthetic engineering is engaged in development and production of artificial technical means of recovery.

The disabled people who transferred such amputation lose first of all an opportunity to self-service, and in most cases also lose a profession.

Therefore purpose of prosthetics of upper extremities: return of the disabled person to a possibility of self-service and to work.

As artificially it is difficult to reproduce all functionality of a healthy human hand at the present stage of technical development, the main objective of prosthetic engineering is a creation of an engineering device capable as much as possible to fill the lost functions, that is to return to the disabled person an opportunity to make the main household movements. Such movements are: gripper and manipulation of a subject.

At amputation at the level of a forearm the full-fledged movement in shoulder and elbow joints remains that is sufficient for very exact positioning of an artificial brush in space without the need for compensation of mobility of a luchezapyastny joint.

Implementation of the gripper requires special technical adaptation which very simple constructional solution is everywhere used now and is a claw in which the second and third finger are integrated and are opposed to the first (the fourth finger and a little finger have no mobility). It is not enough for exact installation of fingers in a subject form, but is enough for deduction of a subject.

The functionality of such prosthesis is defined by management system. The most widespread ways of management are: traction mechanical, miotonichesky and bioelectric ways.

But the main lack of any of these management systems is the lack of a control system of force of the gripper. That is operation of the actuator demands continuous visual control of the made action that, of course, significantly reduces possibilities of use of a prosthesis and quality of life of the patient.

The choice of a method of management depends on specific features of the patient. But in most cases the most optimum and desirable is the bioelectric method as the most physiologic.

Thus, in this work I will describe the main problems of prosthetics in this stage of their development. Then the simplest method of assembly of a prosthesis of an upper extremity, the component part and cost will be provided.

Already on the ready model sentences for improvement of model its pluses and minuses will be submitted. Difficulties of production and nuances are also described.

Chapter 1

The main data about prostheses of extremities

1.1 Digression to history of "a wooden leg"

The most ancient of the known prostheses is the prosthesis of a thumb of a leg made of skin and a tree between 1000 and 600 years BC(Fig 1.1). It belonged to one of the mummies found during excavation of Ancient Egyptian tombs.

Up to the 19th century prosthetics practically did not progress, and prostheses represented only variations on "a piracy subject". During different eras artificial extremities made of different materials: tree, plaster, bronze, metal or silver plates. At the same time prostheses of legs steadily gave the mass of an inconvenience to the owners who at each step had to describe an unbending leg a semicircle. Artificial hands, as a rule, represented the sleeve fixed on a stump to which attached the tool corresponding to a kind of activity of the person: pincers, a hammer, a fighting sword, a motionless brush in a kidskin glove, or a notorious piracy hook.

Fig. 1.1. This prosthesis is nearly 3000 years old.

In the 19th century doctors learned to create the stumps allowing to attach to them more functional prostheses(Fig 1.2). Prostheses also became complicated, thanks to the blocks used at their production, springs and different mechanisms they learned to be bent a little. As a result the wooden leg was not an absolute contraindication of visit of balls any more. Prostheses of hands which form varied depending on a kind of activity of the person allowed not only to earn to themselves a living by unqualified work, but also to write, and even to shuffle cards. Special difficulties were connected with production of prostheses for patients whose hands amputated above an elbow. Work with the help of such prosthesis was possible only at a term of use of the difficult, massive and demanding great physical efforts of devices.

Fig. 1.2. To an artificial hand it is possible to attach something useful.

The majority of the prostheses made now are also the mechanical devices which do not have communication with an organism operating at the expense of strength of the patient. On flexibility and functionality they much more exceed the prototypes, but still do not even approach live extremities. Moreover, some patients are limited to absolutely nonfunctional cosmetic prostheses which main objective is recovery of natural appearance(Fig 1.3).

Fig. 1.3. Wooden leg of the American production.

However the technical revolution of the XX century which made a revolution in many spheres of human life did not avoid also prosthetics. As a result, in the presence of desire and certain financial opportunities, people can pick up to itself the prosthesis not only replacing the lost extremity, but also providing it certain advantages before mere mortals at the same time acting as an ulra-extravagant accessory.

1.2 The current state of the problem

Emergence of the direction which received the name "biomechatronics" was decisive break in the field of prosthetics. The fundamental difference of the prostheses of new generation, or "bionic" ("bioelectric") prostheses generated by it, from normal consists in their ability to register the electric signals developed at reduction of muscles of extremities to which they fasten and to make movements necessary for the person. Thanks to the last achievements of robotics the functionality of such prostheses can even exceed possibilities of live hands and legs. Some of them can be programmed remotely on execution of certain manipulations. Moreover, the design of an artificial hand or leg selected for desire of the patient can, thanks to the silicone covering imitating human skin, to provide almost full masking of a mutilation, or to draw general attention to "person cyborg"(Fig 1.4)(Fig 1.6).

Fig. 1.4. Not distinguish an artificial hand from real.

The latest achievement in the field of prosthetics is development of technology of osteointegration – implantation of prostheses in a bone. Primary benefits of this technology is the lack of risk of rubbing and traumatizing a stump and also almost complete control over an artificial extremity.

Fig. 1.5. Cat Oscar with might and main runs on prostheses.

In the place of an output outside the fragments of such prostheses implanted into bones cover with the special porous material not only imitating the fabric providing connection of a bone and soft fabrics, but also protecting an organism from penetration of infections. However, despite all tricks, osteointegration of prostheses is still connected with high risk of infection today and has the status of experimental. Perhaps, the best-known patient who is quickly running on the osteointegrated prostheses is the cat the Oscar which, having got under the combine, lost both hinder legs. Only the pleasure which the Oscar lost forever is an ability to climb trees.

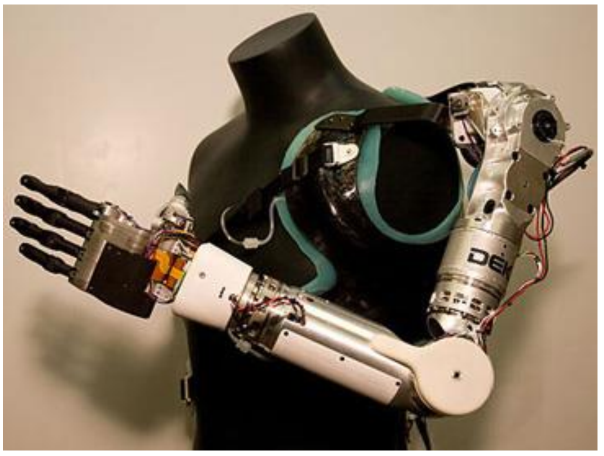


Fig. 1.6. Some like to be cyborgs.

1.3 Prostheses of legs

Knee C-Leg modules of the German firm OttoBock and RheoKnee of the Icelandic company Ossur are the most popular today(Fig. 1.7). A basis of both modules is the hydraulic drive with electric motors managed by the microprocessor by means of the special software. A power supply of all device is provided by the rechargeable battery.

The C-Leg module which appeared in the market in 1997 and already become classics (from "ComputerLeg") is much more functional, than traditional mechanical prostheses. It has three operation modes switched by means of the remote control. The managing director of the module the microprocessor processes information arriving from the pressure sensor and adjusts work of a hydraulic system with frequency of 50 times a minute. As a result of people can not only forget about the artificial nature of the leg during foot walks, but also without problems to climb steps and even to ride a bike.

Fig. 1.7. C-Leg prosthesis which appeared in the market in 1997 already became classics.

The electronic RheoKnee module having artificial intelligence appeared in the market a bit later – in 2006(Fig. 1.8). Thanks to work of complex network of sensors and the microprocessor he independently studies features of gait and, regulating the level of the magnetized liquid in an artificial joint, adapts to it, providing to the owner additional comfort when walking.

Fig. 1.8. XT-9 — a prosthesis for thrill-seekers.

The described knee modules satisfy requirements of most of patients, however it is impossible to forget also about existence of athletes thrill-seekers for whom even amputation of legs is not a convincing argument in favor of failure from a dangerous hobby. Especially for such individuals American diggings of Symbiotechs developed the only product – the knee XT-9 module(Fig. 1.9). This device is inconvenient for walking, but allows to surfboard, mountaineering, to ride a skateboard, a snowboard, skis, ice and roller skates and also many other things. The artificial knee of XT-9 performs function by the

Fig. 1.9. ProprioFoot — the first model of an intellectual prosthesis of a foot which appeared in the market.

four-head of a muscle of a hip, it is bent under pressure created by an extremity, reserving a large number of energy which is spent at extension in a special cylindrical spring and the pneumatic shock-absorber.

Creation of a foot, full in terms of functionality, was the most difficult task when developing an artificial leg. Modern prostheses a foot function at the expense of the complex hydraulic systems imitating position of a foot when standing, walking, run, etc.

The first intellectual prosthesis of a foot which appeared in the market is the ProprioFoot model of the Ossur company. ProprioFoot also independently studies gait of the owner and only for 15 steps adapts to it.

1.4 Prostheses of hands

Bionic prostheses of hands appeared in the market much later of the artificial lower extremities described above. The complexity of reconstruction of small motility of brushes is a basic reason of it. Apparently, the break in this area became possible thanks to new generation of the developers who grew up on the science-fiction saga by George Lucas "Star Wars", to one of the main heroes of which – to Luke Skywalker, – despite the lost hand, it was succeeded to become the greatest soldier.

The proof of it is the supermodern prosthesis of LukeArm ("Luke's Hand") offered by the DekaResearch company(Fig. 1.10). This surprising device does not need neither accumulators, nor an electric motor as works at the expense of the miniature rocket engine for as which fuel serves hydrogen peroxide when which heating the steam opening and closing the valves connected to prosthesis joints is selected.

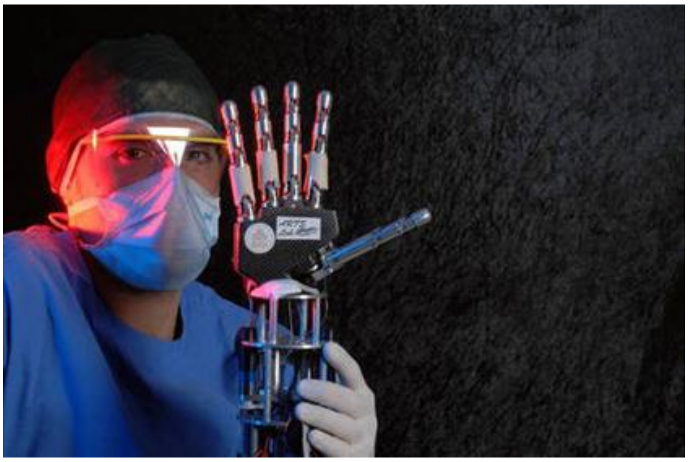


Fig. 1.10. LukeArm — development of generation of "Star Wars".

One more miracle of biomechatronics is the artificial hand of SmartHand developed by the international group of scientists and for the first time tested in 2009 at the university of Tel Aviv(Fig. 1.11). The feature of this prosthesis is that, thanks to operation of four electric motors and 40 sensors, it not only imitates the movements of a hand of the person, but also reproduces feelings from touch to objects.

Fig. 1.11. The prosthesis of BeBionic is controlled as well from the control panel.

One more of most the last developments – a prosthesis of the BeBionic company – not only is capable to execute all commands sent by nervous system, but also is equipped with the remote control by means of which the user can independently configure functions of a hand, regulate force of compression of fingers, etc(Fig. 1.12).

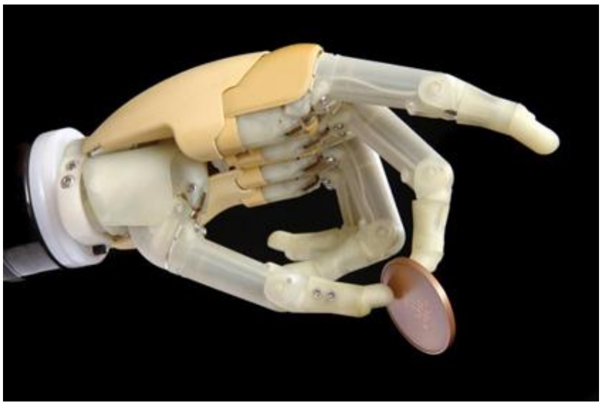


Fig. 1.12. i-LIMB Hand – the only bionic prosthesis of a hand put on a flow.

However the only bionic prosthesis of a hand which production is put "on a flow" is the artificial hand of i-LIMB Hand of the Scottish company TouchBionics which appeared in the market in 2007 and its ProDigits option developed for a year later applied to prosthetics of fingers. Thanks to the sensor and miniature electric motors registering the nervous impulses sent by muscles such prostheses imitate a set of functions of a human hand. The last modification of a prosthesis of i-LimbPulse which appeared in the summer of 2010, except the strengthened construction capable to hold a load up to 90 kg, and bigger mobility, differs from earlier models in existence of Bluetooth by means of which movements of a prosthesis and settings of reaction to muscular impulses it is possible to configure depending on needs of the patient.

1.5 Cyborgs among us

One of the brightest characters personifying the present stage of prosthetics is the American of AimeeMullins who was born in 1976 who because of a congenital disease at one-year-old age had to amputate both legs below a knee(Fig. 1.13). In student's years the girl achieved the giving-out results in track and field athletics competitions where she took part on an equal basis with healthy athletes. It also came to a podium as model and acted in several movies. However its popularity is caused mainly by the fact that she tried to obtain all the achievements on beautiful legs prostheses.

Fig. 1.13. Prostheses of the athlete and model of Aymimallins.

It is necessary to mention also the southern African runner Oscar OskarPistorius, also in the early childhood lost both legs below a knee. Thanks to fibrokarbonovy prostheses of special construction he became the winner of numerous paraolympic runnings. In January, 2008 OskarPistorius was forbidden to participate in normal competitions as the expertize which is carried out by specialists showed that prostheses give him certain advantage before normal athletes(Fig 1.14). However the 22-year-old runner did not give up, submitted the appeal and in May, 2008 carried the case then to it allowed to undergo selection on the Olympic Games of 2008. Unfortunately, OskarPistorius did not manage to execute standards, however he hopes to participate in the Olympic Games of 2012 in London.

Fig. 1.14. A prosthesis for the climber.

A cult personality for users of prostheses is the American climber, the engineer-biophysicist, the associate professor of the Massachusetts Institute of Technology Hugh HughHerr to whom in 1982 at the age of 17 years amputated both shins freezed during climbing ascension. Since then he is obsessed with creation of prostheses of the lower extremities in all respects exceeding the real legs (he is one of creators of the knee RheoKnee module mentioned above). HughHerr is the owner of the whole arsenal of "legs" of own development. In normal life it uses prostheses with the springs hidden in shoes from carbon fiber which for morning jogs replaces with long carbonic arcs. Correct to a youthful hobby HughHerr invented a set of special climbing prostheses, including the long aluminum prostheses with small rubber foot turning it into the giant of 2.1 m in height, prostheses with foot in the form of aluminum claws and wedge-shaped prostheses ice axes from polyethylene(Fig. 1.15). [1]

Fig. 1.15. The prosthesis helped Hugh Gerr to be engaged in rock-climbing.

Chapter 2

Ways 3D of scanning of extremities

Before this point I will describe ways of fastening of a prosthesis to a body. on the matter there is not enough information and I came to a conclusion that at each production of the device the method of fastening differs. But the main ways I selected three:

- fastening with use of straps;
- fastening with use of silicone laying;
- fastening of an artificial extremity directly on a bone.

All cases require a 3D model of the injured extremity. For this purpose we will consider ways of scanning and creation of 3D objects.

2.1 3D scanner

2.1.1 What is the 3D scanner?

The 3D scanner is a device which analyzes a physical entity and, making a start from the acquired information, creates its 3D image. The scanned models can be processed further by means of a CAD then are used for technological and engineering developments. For creation of a 3D model are used the 3D-printer and 3D - the monitor.

Several technologies, different among themselves participated in creation 3D - the scanner at once. The objects which are exposed to digitization also have some restrictions. Difficulties can arise with smooth, brilliant or transparent surfaces. It is worth reminding that three-dimensional data are important also in other fields of activity. For example, it is used in the entertaining industry: during creation of video games, movies, drawings. 3D - technologies find the application in orthopedic area and prosthetics, when developing industrial design, a reverse engineering, creation of prototypes and also in survey and the documentary reporting of historical objects or other cultural artifacts.[2]

2.1.2 Area of functionality 3D - the scanner

During operating time 3D - the scanner creates a set of points according to geometrical proportions of the scanned object. Further these points recreate a subject form, that is reconstruct it on the monitor. If there are data on coloring, then they define also color of future digital surface.

3D - the scanner can be compared to the normal camera: the viewing field at them cone-shaped type, and information can be obtained only from those surfaces which were not darkened. Differences between these devices nevertheless essential. The camera renders only the image and color of a subject, and the scanner, investigating an object more carefully, issues "picture" with exact distance of each point to a surface. It allows to see the image in three planes at once.

For full modeling of a subject of one scanning, as a rule, insufficiently. Several such operations are required at once. Scanning of an object from the different directions is necessary for obtaining more complete information about its parties. All scanned data are imposed on the general coordinate system where there is "binding" and alignment of the image. All procedure of modeling is called the 3D pipeline.

For accurate scanning of an object and scanning of its forms there are several technologies. On classification 3D - scanners are divided into two types:

contact scanners and contactless. The last, in turn, are divided into two views – passive and active.

2.1.3 Contact 3D - scanners

Scanners of this look study an object directly – through physical interaction. At the time of the research the subject is on the special testing plate polished and ground to the necessary roughness of a surface. If the thing asymmetrical or cannot exactly lie on one place, it is held by special clips (vice).

Distinguish three forms of the 3D mechanism - the scanner(Fig. 2.1):

1. The carriage equipped with a measuring hand which is accurately recorded in the perpendicular direction. The research on all axes takes place while the hand moves along the carriage. This option is ideal for studying of flat or normal convex surfaces.
2. The device equipped with the high-precision angular sensor and the recorded components. The end of a measuring hand is located so that it is capable to reproduce the most difficult mathematical calculations. This mechanism is optimum for the scanning of internal space of an object or other its deepenings having small inlet opening.
3. One-time use two above-stated mechanism. For example, the manipulator combine with the carriage that allows to collect information from the large objects having several internal compartments or, blocking each other, the planes.

Fig. 2.1. Sample 3D Contact Scanner

The coordinate measurement machine – a striking example 3D - the scanner of contact type. They are ultraprecise and are widely applied on different productions. It is possible to refer need of obligatory contact with the studied object to essential minus of the machine. Probability of damage of a subject or its deformation is high. This point is very important if there is a scanning of a fragile or historical object.

One more shortcoming the testing and assessment material is her sluggishness. Movement of a hand on the set purpose can happen very long. While modern optical models, can work much quicker.

It is also possible to carry to this group manual measuring devices which are often used for 3D - modeling of animation movies.

2.1.4 Contactless active 3D – scanners

For operation of the active scanner either normal light, or a certain type of radiation are used. Through the passing radiation or reflection of light, an object is exposed to a digital research. There is an application of X-rays or ultrasound(Fig. 2.2).[3]

Fig. 2.2. Example of a contactless 3d scanner

2.1.5 Triangulable scanners

These devices use a laser beam for sounding of an object (Fig 2.3). The scanner sends a beam regarding, and separately fixed camera enters data on arrangement of the specified point. In process of the movement of the laser on a surface, the camera view fixes a point in different places. Triangulable they were called because the laser radiator, finishing point and the camera, jointly form a triangle(Fig. 2.3).

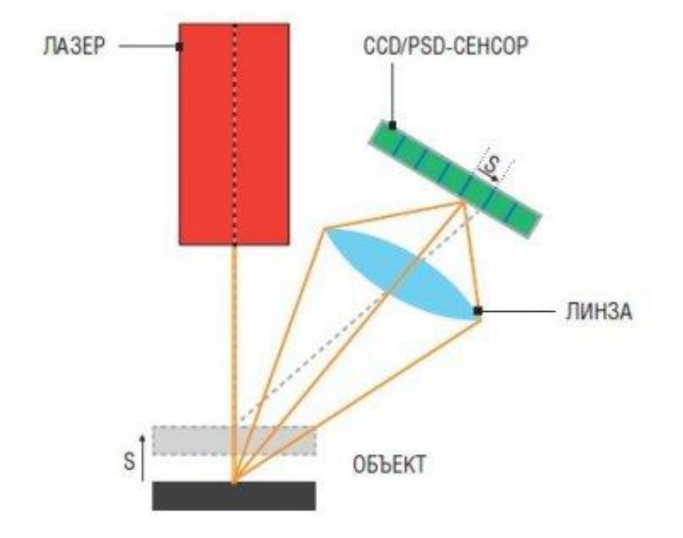


Fig 2.3. Triangulable scanners

2.1.6 Laser 3d scanner 3D - scanners

It is an active type of the scanner which for a research of an object uses a laser beam. The vremyaproletny range finder is its cornerstone. It defines distance to a surface, calculating time for which the laser flew by there and back. In this case the laser beam is used as a light pulse which time of reflection is measured by means of the detector. Light speed, as we know, a constant therefore, knowing for what time the beam makes flight there and back, it is possible to calculate without effort distance from the scanner to a surface of the studied subject.

Laser 3d scanner 3D - scanning devices in one second are capable to measure to 100,000 points. [4]

2.2 Photogrammetry

2.2.1 What is a photogrammetry?

If in brief, then it is process of creation of 3D models of several images of one object photographed from different corners.

Though this equipment is not new at all, it is much older than modern process, and it was widely used in cartography and geodesy. It became more popular thanks to availability because of increase in power of computers that allowed it to extend to other areas, such as video effects and development of games. [5]

2.2.2 How to create models by means of photos

To receive materials in the program creating 3D models on the basis of data of the photo it is necessary to make photographing of the necessary object for loading. The photogrammetry can be used absolutely for any three-dimensional models, and proceeding from its type and it will be required to select a shooting method. If it is a separate object (for example, any archeological find which requires reconstruction), its shooting is made manually. The same is fair also for many other, and here if visualization of an exterior in 3D max is planned or creation of a three-dimensional landscape, there will be more effective a shooting by means of the quadcopter equipped with the camera.

The method of a photogrammetry is based on loading of the received photos in the programs intended for creation of three-dimensional models on the basis of these images and from what program is going to be used, both the quantity, and features of pictures will depend.

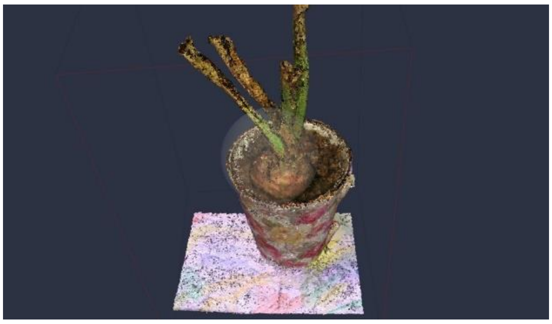


Fig. 2.4. The 3d model created from photos

On the basis of the received photos loaded into the program the three-dimensional model of an object is created (Fig. 2.4)

The following programs are most often used:

- Autodesk Remake. There are two versions of this product and if you want to test possibilities of this program, it is possible to use the free version which has restriction in 125 images for one project. Free Autodesk Remake allows to work only in a cloud, but if the program suits you and you want to buy the license, your opportunities will extend up to 250 images on the project, and instead of cloudy processing you will be able to create three-dimensional models and offline.
- Really Capture. The distinctive feature of this application — the high processing speed which became possible due to function of fast building at the same time from the computer on which processing is made is not required high powers at all. There are two versions of the license of this application and if you do not need to process more than 2500 images on the project, then you are required to buy the license for 3 months for 99 euros, and here the version for more large-scale works, for example creation of three-dimensional scenes of the area or difficult architectural objects, will cost already 7500 euros for a year of use.
- Agisoft Photoscan. Very popular option with the clear interface, lack of restriction the number of images for one project. During the work with this program it is necessary to consider that the number of photos directly influences also the recommended power of the computer used for processing and for a while which is required for creation of models.
- Pix4d — the program which is most often used for creation of 3D models of industrial function. Works slightly quicker than the previous option, besides it is capable to process more than 2500 images for one project.

In addition to paid programs for a photogrammetry there are different free options which will suit those who wish to understand in practice, than differ, for example, visualization of the house in model of the same building, 3D max от creation, according to photos.

2.2.3 Pluses and minuses of the Photogrammetry

Undoubted advantage of a photogrammetry is a saving of time in comparison with normal modeling that is especially felt during the work with scenes or objects, large-scale and difficult on geometry, for example, by big buildings or the whole landscape scenes. Thanks to the program which analyzes the received pictures and creates three-dimensional model it is possible to get rid of creation of the same model from scratch and, having received polygonal model, to pass to its editing.

The photogrammetry allows to save time for creation of models of objects with difficult geometry

One of difficulties which it is possible to face, applying this method, is how it is correct to carry out shooting of an object. To create model, it is necessary to remove an object so that to provide about 60% of overlapping between the next frames; thus we take several tens of the picture for one circle, and such circles can be a little. Besides, it is recommended to avoid the excess objects getting into the shot that then not to spend a lot of time for cleaning of textures. [6]

Chapter 3

Executive position control systems

3.1 Principles of Position Control Systems

Position control systems have a very wide range of applications. They are used in various industrial installations and works as antenna guidance systems, optical radio telescopes.Many executive motors from units to hundreds of kW, their power is supplied from electric machine, thyristor converters, transistor power amplifiers. Position control is carried out using sensors that, in analog or discrete form, provide information on the movement of the working body throughout the journey. As sensors, selsins, pulse and digital sensors, etc. are used. In most cases, powerful industrial drive position control systems are built according to the principles of subordinate control . (Fig. 3.1) CS position in which when switching the switch P is the closure of the analog or digital circuit.

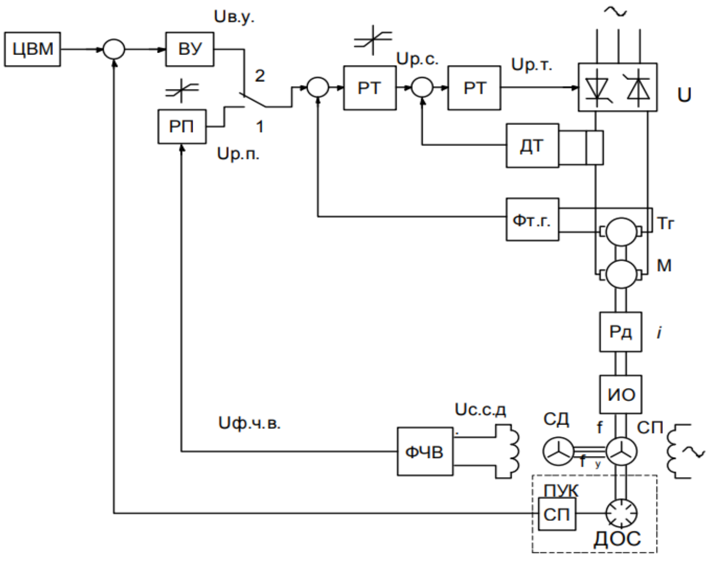


Fig. 3.1. - Diagram of the position control system

In the first case, the measuring elements are selsyns operating in transformer mode. The Selsyn receiver (SR) is connected to the executive body (EA), which is driven from the engine (M) via the RD gearbox . The input to the control input, which is the rotation of the sensor selsyne (SS) at a certain angle φ_y relative to SR , causes an ac voltage $U_{ss\ to}$appear on its single-phase winding , the value of which is determined by the value of the error angle ¸ and the phase - by the direction of rotation (angle sign) . With a phase - sensitive rectifier (PSR) the voltage is rectified, the polarity U_{PSR} is determined by the mismatch sign. The voltage appears at the output of RC , acting on the input of the speed circuit, and the motor rotates, working off the mismatch until the equality $\varphi = \varphi_y$

When limiting the input voltage RC value U_{lim} maximum engine speed does not exceed the rated value ω_n

In a digital position loop, the measuring element is a discrete feedback sensor (DFS). Using the conversion circuit (SR), it removes the signal in binary code, due to which the sensor together with the conversion circuit is an angle-code converter (ACC) or a linear displacement-code converter. The computational device (CD), comparing the digitally prescribed value and the true value, determines the error code and digitally generates a correction signal, converting the result of the calculations into a voltage acting on the input of the speed loop. The most promising direction in creating digital position control systems is the use of control DCs .

According to the principle of operation, DC performs the necessary mathematical operations for a certain time, called the discontinuity period. If DC solves the complex tasks of managing the entire process and the system under consideration is one of the local systems, then the discontinuity period will not be made sufficiently small and the use of DC in the control loop is irrational. The PCS is then run autonomously, and the DC generates the prescribed value of movement in digital form.

In the digital control loop, the magnitude of the value obtained by mathematical operations for a period of discreteness remains unchanged in the subsequent period of discreteness. There is a time-slicing process (the process of transforming a continuous function of time into a step function). The digital representation of quantities is characterized by the fact that it is possible to fix not any values of a quantity, but a series of values that differ from each other by a unit of the lower order. This is the level quantization. So the digital circuit is a nonlinear discrete system.

In the general case, the structure of the digital position control system (PRS) is presented in the form (Figure 3 .2). Digital correction devices DCD 1 and DCD 2 process information in DC and CD , respectively , implementing the adopted control laws. Links of constant delay $e^{\tau 1 p}$ $e^{\tau 2 p}$ $e^{\tau 3 p}$ take into account the time taken by DC , CD andACC to process information.

The effect of time-slicing is taken into account by the introduction of pulse elements (keys), with discrete periods T1, T2, T3. The level quantization is carried out by nonlinear elements NE1, NE2, NE3, having a relay characteristic with the number of steps $N = 2^{\alpha}-1$, where α is the number of binary digits used. Extrapolator E converts a discrete signal into a continuous one. Extrapolation - (Latin. Straighten, change) finding the function values at points outside the interval containing the known values of this function. The extrapolator output voltage acts on the analog unchanged part of the position loop with the transfer function $W_{\mu}(p)$.[7]

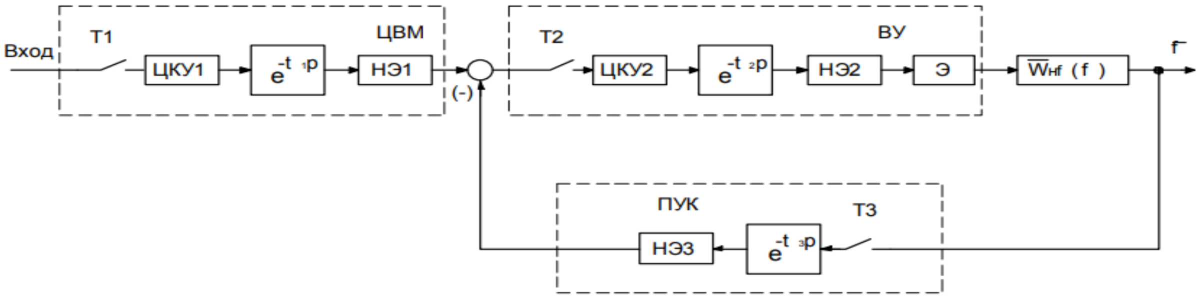


Fig. 3.2. - The structure of the digital control system position

3.2 PCS mechanism in positioning mode

Setting in the mode of small displacements

Positioning is the PCS mode of operation in which the task of the system is to move the working body of the mechanism from one fixed position to another. When considering the positional system distinguish (Fig. 3.3):

a) small displacements in which none of the regulators is limited and the system works as linear;

b) the average displacements at which mining occurs when the PC is limited, i.e. when limiting the armature current, but the area of work with a constant speed is missing;

c) large displacements, in the course of which the engine runs for a certain time at a steady speed as a result of the RC limit , and the RS is limited during acceleration and deceleration.

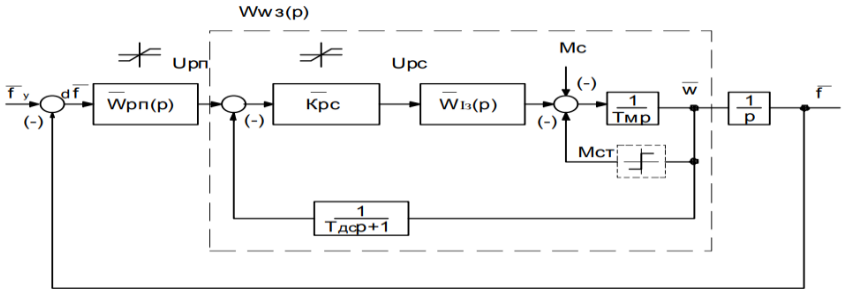


Fig. 3.3. - Block diagram of the position control system

We will consider the settings of the position contour in the baseline , the basic values

Мб=Мн, $\omega_Б = \omega_Н$; $I_{ЯБ} = M_Б / C_Д$ и $U_{ДСБ} = k_{ДС} \cdot \omega_Н$; $U_{РПБ} = k_{ДС} \cdot \omega_Н \cdot R_{ЗС} / R_С$, where Rsc and Rc are input resistors RS. The base value of the angle - the angle through which the shaft will rotate executive at constant motor speed ω $_{B.}$ Then the angle of rotation through ω $_D$ to express in o.e , ϕ = ω (t $_Б$ / p) (the equation connecting the speed of the engine and the angle of rotation).[8]

If in the analog position loop to take the base voltage value of a phase - sensitive rectifier U $_{FCh.VB}$ k $_{SF.\ WB}$ K $_{CC}$ ϕ $_C$ then the transfer function of the open position loop will be:

$$W_P(p) = \overline{W}_{РП}(p) \cdot \overline{W}\omega_з(p)\frac{1}{t_б p} .$$

We replace the closed-loop speed with an aperiodic link (to determine the RC parameters), therefore, to adjust the system on the OM, we use the proportional controller RC .

Conveniently for the base value of time t $_\delta$ = 1s , then:

$$\overline{k}_{РП} = 1/T_{\omega э} \tag{3.1}$$

Relation between RC gain in relative units and alternative units. at t $_\delta$ = 1s is obtained in the form:

$$\overline{k}_{pn} = k_{pn}\frac{k_{ф.г.в.}k_{cc}\varphi_\delta}{\dfrac{R_{з.с.}}{R_c}k_{д.с.}\omega_\delta} = k_{pn}\frac{k_{ф.г.в.}k_{cc}R_c}{k_{д.с.}R_{з.с.}i} . \tag{3.2}$$

The block diagram of the system when writing variables in relative units and assuming assuming that the motor EMF feedback can be neglected is shown in

Figure 3 .3. Since the numerator has the dimension of time, the RC coefficient in relative units is dimensionless. When acting on the mechanism of the active moment of load MC, the specified position is supported with a static error. In statics, when ω = ϕ = 0 and the transfer coefficient of a closed current loop is equal to one, it is determined

$$\delta\overline{\varphi}_{ycm} = \frac{1}{\overline{k}_{P\Pi} \cdot \overline{k}_{PC}} \cdot \overline{M}_C \ .$$

In this case the fixed anchor, the motor current corresponding to the value of the load torque $i = {}_I M_{C}$.

However, usually for positioning systems, the mode of small displacements is not characteristic, and the choice of the value of the RC transfer coefficient according to the formula (3.1) for medium and large displacements may not provide the required nature of mining.[9]

3.3 Positioning system during the development of medium and large displacements

Implementing the required law of displacement

When considering the development of a system of medium and large displacements, a simplification is usually made: we assume that the current loop has high speed and the filter time constant T_{gc} tachogenerator: $T_{DS} = 0$, i.e. $T_{\mu\omega} \rightarrow 0$ of the investigator but the transfer coefficient RS k_{RS} $_{RS}$ $_{is}$ large. Then a small voltage at the RC output leads to a limitation of the PC.

Let at time t_0 , the task is fed to the system input (see Figure 3.4) to move ϕ_Y ; if it is large, the voltage at the RC output will reach the limit U_{ppOgre} , immediately limited to the PC.

At the moment of time $t_{2,\text{ the}}$ speed will become ω_1 , and the displacement will reach ϕ_1 , at which the equality

$$\bar{k}_{РП}(\bar{\varphi}_У - \bar{\varphi}_1) = \bar{\omega}_1 , \tag{3.3}$$

Hose the RC signal and the speed feedback signal are equal to each other. At the next time point, the feedback signal will exceed U_{pn} and the voltage at the output of the RS, and therefore the armature current will change sign. The deceleration will end at the time t_3 , when the error is “0”. RC gain is defined as (Figure 3.4):

$$\bar{k}_{РП} = 2\cdot\sqrt{\frac{\bar{I}_{Я.MAX}}{T_M\varphi_У}\cdot\frac{\bar{I}_{Я.MAX}+\bar{M}_{CO}}{\bar{I}_{Я.MAX}-\bar{M}_{CO}}} \tag{3.4}$$

This means that the value of k_{RC} , which ensures the processing of a given displacement, is different for different displacements ϕ U and values of the load moment M_{C0} . For other values of a given displacement and a constant RC k, the velocity graph is different from the triangular one.

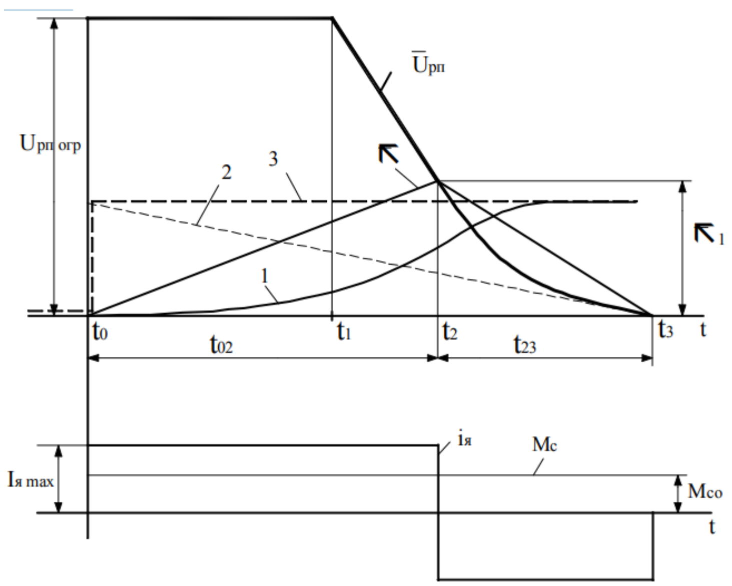


Fig. 3.4. - Position Management System Graphics

If employed proportional RC, the processing determined based on the requirements of a triangular chart speed adjusting movement, ie one in which $\omega_1 = \omega_N$; $\omega_1 = 1$; $M_C = 0$.

Based on the expression:

$$\bar{\varphi} = \bar{\varphi}_y = T_M \bar{\omega}_1^2 \frac{\bar{I}_{Я.MAX}}{\bar{I}^2_{Я.MAX} - \bar{M}^2_{C0}}, \tag{3.5}$$

Substituting $\phi = \phi_{y.nast}$ k expression $_{RC \ is}$ obtained required to provide a triangular graph of the speed when adjusting the movement of the transfer coefficient RC :

$$\bar{k}_{PП} = \frac{2\bar{I}_{Я.MAX}}{T_M}. \tag{3.6}$$

In this case, t_1 coincides with t_2 . All movements, less than the adjustments, will be worked out with the achievement of the pressure , but there is no overshoot, undesirable in the positioning systems. Movements that exceed the adjustments will be large. Then the middle part of the movement will be worked out with a constant equal to the nominal speed and the speed graph will become trapezoidal .[10]

3.4 Parabolic position controller

A close to a triangular velocity graph for any lower tuning value of the displacement can be obtained using RC with a nonlinear static characteristic. Consider the ideal idle mode when $M_{with} = 0$. Then, in accordance with (3.5), you must choose:

$$\bar{k}_{PП} = 2\sqrt{\frac{\bar{I}_{Я.MAX}}{T_M}}.$$

In this case, the velocity graph is an isosceles triangle and, when going from acceleration to deceleration, the displacement will be $\phi_1 = \phi_y / 2 = \delta\phi$. RC output voltage :

$$\overline{U}_{РП.1} = \sqrt{\frac{4\overline{I}_{Я.MAX}}{T_M 2\overline{\varphi}_1}\delta\overline{\varphi}_1} = \sqrt{\frac{2\overline{I}_{Я.MAX}}{T_M}\delta\overline{\varphi}}.$$

To perform equality for any values of $\phi_{V,}$ use RC with a nonlinear static characteristic, from the expression

$$U_{РП} = \sqrt{2\overline{I}_{Я.MAX}\delta\overline{\varphi}/T_M}\ . \tag{3.7}$$

Fig. 3.5, a shows the nature of changes in the basic coordinates of the system in this case.

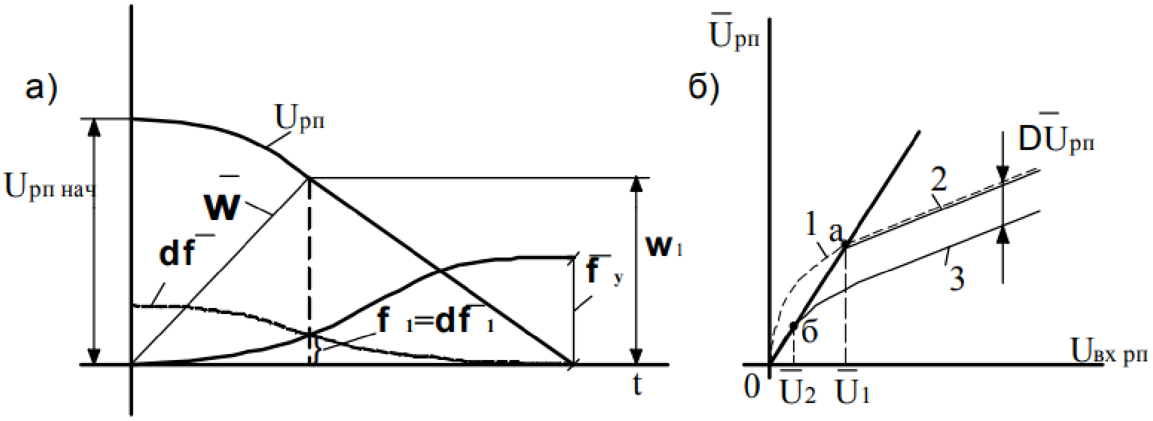


Fig. 3.5 - The nature of the change in the coordinates of the system with a triangular law and the characteristics of a parabolic controller

In the braking section, the relative speed and voltages RC vary according to the same linear law, regardless of the value of ϕ_y . Actually in a real system

U_{RC} over most of the deceleration section will exceed ω by some amount sufficient for the RS having a finite gain factor to be limited, which ensures a linear law of velocity variation. Nonlinear static characteristic RC constructed in accordance with (3.7) and taking into account the fact that $U_{FPVH} = \delta\phi$ is shown in Figure 3.5, b (curve 1).

At $U_{FPVh} \rightarrow 0$, the gain RC should theoretically become infinitely large. Due to this, an attempt to use the calculated characteristic would lead to instabilities of the system in a coordinated position. To avoid this, the initial part of the characteristic is made linear (straight line 0 b a) and corresponding to the gain when adjusting the position contour to optimum modulo. As a result, characteristic 2 is obtained with a kink at point a at the input voltage RC $U_{FPVH} = U_1$. The actual operating conditions of the system differ from those considered idealized, on the one hand, by the presence of a moment of static resistance, and on the other hand, as a result of the limited speed of the current loop and the final gain RS, the change in the armature current is from + I_{max} before - I_{min} does not happen instantly, but for some time. In order to avoid overshoot at the same time, it is necessary to begin braking earlier than in the idealized case. With this in mind, we propose to combine the linear and nonlinear parts of the characteristic at the point δ, and lower the nonlinear part of the characteristic by the value ΔU of the $_{RP}$ with respect to curve 2 (characteristic 3). The nonlinear characteristic is realized by including the corresponding nonlinear link in the RC feedback circuit .

3.5 Mechanism of position control in tracking mode

Task tracking control

The task of the follow-up control is to ensure the movement of the executive body (EA) in accordance with the control action varying according to an arbitrary law with an error not exceeding the permissible value in all modes under the conditions of an effect on the disturbance system. In tracking mode, none of the controls should be limited.

24 Errors in the processing of control action.

Usually, the accuracy of the tracking system when controlling is evaluated by the accuracy of reproduction of the input signal, which varies with a constant speed, with a constant acceleration or harmonic law. Usually, based on the requirements for a specific tracking system, the designer sets the required Q-values of the system for speed and accelerationDω and Dε, which characterize errors, respectively, when working on a linearly varying input signal in a system with first-order astatism and a signal varying with constant acceleration to a second-order astatism system. If the order of astatism is equal to one, then the transfer function of the open-loop system can be written in general form as follows:

$$W(p) = \frac{1}{a_1 p} \cdot \frac{b_m \cdot p^m + \ldots + b_1 \cdot p + 1}{\frac{a_n}{a_1} \cdot p^{n-1} + \frac{a_{n-1}}{a_1} \cdot p^{n-2} + \ldots + \frac{a_m}{a_1} \cdot p^{m-1} + \ldots + \frac{a_2}{a_1} \cdot p + 1}.$$

The speed factor is the value: Dω = 1 / α_1 . The set value will be satisfied by the system, the low-frequency asymptote of the AFC which has a slope of -20 dB/dec, intersects with the x-axis at a frequency equal to Dω . In a system with second-order astatism, where:

$$W(p) = \frac{1}{a_2 p^2} \cdot \frac{b_m \cdot p^m + \ldots + b_1 \cdot p + 1}{\frac{a_n}{a_2} \cdot p^{n-2} + \frac{a_{n-1}}{a_2} \cdot p^{n-3} + \ldots + \frac{a_m}{a_2} \cdot p^{m-2} + \ldots + \frac{a_3}{a_2} \cdot p + 1}.$$

Acceleration quality factor: D ω = 1 / α_2

The low-frequency asymptote of the corresponding LAFH has a slope of –40 dB / dec and intersects the abscissa axis at a frequency equal to D ε .

System error when processing the harmonic signal $\phi_y = \phi_{ym} \sin \Omega_{MAX}\, t$ in a non-linear tracking system, it is also determined based on the AFC of an open-loop system. Since the amplitude frequency response at each given frequency is the ratio of the amplitudes of the harmonic signals at the output and input of the system, we can write:

$$20\lg\left|\frac{1}{1+W(j\omega)}\right|_{\omega=\Omega_{макс}} = 20\lg\frac{\delta\varphi_m}{\varphi_{Ym}},$$

where $\delta\phi_m$ is the amplitude of the error, also harmonically varying with frequency Ω_{max} .

The tracking system is constructed in such a way that its cutoff frequency of the AFC significantly exceeds the maximum frequency of the harmonic input signal, since only in this case it will work it out satisfactorily. This gives grounds to neglect the unit compared with the amplitude value max $| W (j \omega) | \omega = \Omega_{max}$.

Then approximate equality is true:

$$20\lg|W(j\omega)|\omega = \Omega_{макс} \approx 20\lg\frac{\varphi_{Ym}}{\delta\varphi_m},$$

those. the smaller the error should be at a given input action, the greater should be the amplitude of the frequency response of an open-loop system at a frequency $\omega = \Omega_{max}$. This allows you to build the desired AFC system so that the specified requirements on the accuracy of the control action are satisfied.

Improving the accuracy of control processing through the use of combined control

The possibilities of increasing the accuracy of the tracking system by increasing the Q-factor or the order of astatism are limited. The increase in Q, i.e. with this type of transfer function, the cutoff frequency of the AFC of an open-loop system is limited by the influence of small time constants. In addition, as k (β) increases , the range of input signals for which the system operates as linear decreases, and the influence of interference increases. Increasing the order of astatism at a given cutoff frequency improves the accuracy of testing low-frequency harmonic control actions. However, increasing the order of astatism leads to a decrease in the stability of the system. An effective means of increasing the accuracy of the tracking system is the use of combined control, in which one or more derivatives of it are introduced into the system along with the task of movement. Let the part of the system, to the input of which a compensating signal is entered through a compensating channel with the transfer function $W_{K1}(P)$, has the transfer function $W''(P)$, and the transfer function $W'(P)$ is defined as $W'(P) = W(P) / W''(P)$, where W (P) is the transfer function of the open-loop system (Figure 3.6).

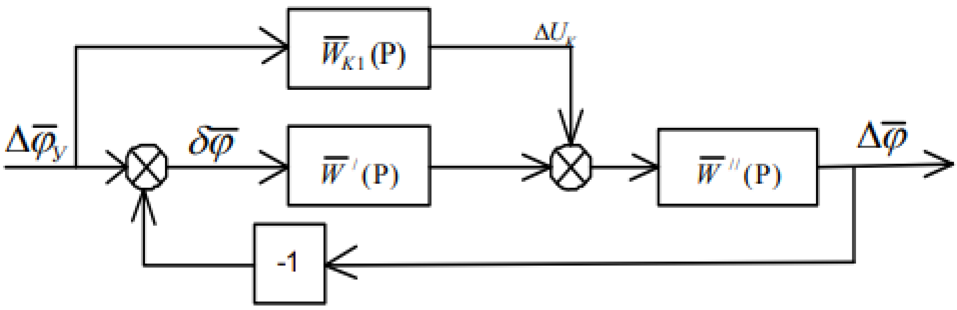


Fig. 3.6. - Block diagram of a system with a combined control

Based on the expression:

$$\Delta\overline{\varphi} = \overline{W}''(P)\cdot[\overline{W}'(P)(\Delta\overline{\varphi}_y - \Delta\varphi) + \overline{W}'_{K1}(P)\Delta\varphi],$$

and taking into account the fact that $W(P) = W'(P) * W''(P)$, the control transfer function for a closed-loop system with a compensating channel can be written in the form:

$$\overline{W}_з(P) = \frac{\Delta\overline{\varphi}}{\Delta\overline{\varphi}_y} = \frac{W(P)}{1+W(P)}[1+\frac{\overline{W}'_{K1}(P)}{\overline{W}'(P)}] \quad (3.8)$$

Introducing the concept of equivalent transfer function $W_e(P)$ as a transfer function of an open-loop system, in which a similar control transition would have been obtained without introducing a compensating channel, we can write:

$$\overline{W}_З(P)=1+\frac{W_Э(P)}{W_Э(P)},$$

whence with (3 .8):

$$W_Э(P)=\frac{\overline{W}_З(P)}{1-\overline{W}_З(P)}=\frac{W(P)[1+\overline{W}_{K1}(P)/\overline{W}\ \ (P)]}{1-\overline{W}^{//}(P)\overline{W}_{K1}(P)}]. \tag{3.9}$$

The error of the combined system is estimated based on the transfer function:

$$W_\delta(P)=\frac{\delta\overline{\varphi}(P)}{\Delta\overline{\varphi}_Y(P)}=\frac{\Delta\overline{\varphi}_Y(P)-\Delta\overline{\varphi}(P)}{\Delta\overline{\varphi}_Y(P)}=\frac{1-\overline{W}^{//}(P)\overline{W}_{K1}(P)}{1+W(P)}. \tag{3.10}$$

This expression allows you to write the condition of identical equality to zero errors in the control, that is, the condition of the system invariance with respect to the control:

$$\overline{W}_{K1}(P)=1/\overline{W}^{//}(P). \tag{3.11}$$

In fact, due to the fact that the closed speed loop is not an aperiodic link, but a complex dynamic system, complete invariance is not achieved. We estimate the result of applying the compensation channel with the transfer function:

$$\overline{W}_{K1}(P)=\frac{T_M}{\overline{K}_{PC}}P^2+P, \tag{3.12}$$

n the real system, with the transfer function of the closed loop speed W $_{\omega Z}$ (P) .

The transfer functions of the equivalent open-loop system and errors can be obtained by transforming formulas (3.9) and (3.10)

$$W_Э(P)=\frac{\frac{T_M}{K_{PC}}P^2+P+\overline{K}_{PП}}{P[\frac{1}{\overline{\overline{W}}_{\omega З}(P)}-\frac{T_M}{\overline{K}_{PC}}P-1]}\quad;\quad W_\delta(P)=\frac{P[\frac{1}{\overline{\overline{W}}_{\omega З}(P)}-\frac{T_M}{\overline{K}_{PC}}P-1]}{\frac{P}{\overline{\overline{W}}_{\omega З}(P)}+\overline{K}_{PП}}.$$

Let the speed and position contours have a standard setting for optimum modulo. If the time constant of the filter of the tachogenerator T $_{дс}$ = 0, then the coefficients of the speed and position regulators should be chosen in accordance with the expressions:

$$\overline{K}_{РП} = 1/T_{\omega Э} = 1/4T_{IЭ} = 1/8T_{\mu l}\,; \ \overline{K}_{PC} = \frac{T_M}{2T_{1Э}} = \frac{T_M}{4T_{\mu 1}}. \tag{3.13}$$

With a sufficient degree of accuracy, a closed current loop can be described by the transfer function:

$$\overline{W}_{I3}(P) = \frac{1}{2T^2_{\mu l}P^2 + 2T_{\mu l}P + 1}. \tag{3.14}$$

Then the transfer function of the open speed loop will be:

$$W_{\omega}(P) = \overline{K}_{PC}\overline{W}_{I3}(P)\frac{1}{T_M P} = \frac{1}{4T_{\mu l}P[2T^2_{\mu l}P^2 + 2T_{\mu l}P + 1]}, \tag{3.15}$$

and closed:

$$\overline{W}_{\omega з} = \frac{1}{4T_{\mu l}P[2T^2_{\mu l}P^2 + 2T_{\mu l}P + 1] + 1}. \tag{3.16}$$

After substitution of expressions we get:

$$W_{э}(P) = \frac{32T^2_{\mu I}P^2 + 8T_{\mu I}P + 1}{(4T_{\mu I}P)^3(T_{\mu I} + 1)};$$

$$\delta\overline{\varphi} = \frac{64T^3_{\mu l}P^3(T_{\mu l}P + 1)}{8T_{\mu l}P[4T_{\mu l}P(2T^2_{\mu l}P^2 + 2T_{\mu l}P + 1) + 1]}\overline{\varphi}_{У}.$$

An increase in the control response rate due to the combined control with incomplete invariance is accompanied by an increase in oscillation . So, in this case, the overshoot during the development of a stepped control action (curve 1, figure 3.8) is about 55%, while in the absence of a compensating signal, the transition process corresponds to the setting for OM (curve 3) and the overshoot is about 4% . The introduction of the compensation channel significantly improved the accuracy of the harmonic input signal. If, for example, the input signal has a frequency $\Omega_{MAX} = 0.05 / T_{\mu I}$, then the error a decreases 50 times (points A ' and A '' in Figure 4 .7).[11]

The implementation of two derivatives of the input signal without delay presents technical difficulties. Given this, it is advisable to estimate the effect that can be obtained in the system under consideration as a result of introducing only one derivative of the input signal at $W_{K1}(P) = \tau_1 P$. After substitution of this expression in 6.10 the error is obtained in the form:

$$\delta\overline{\varphi} = \frac{64T^4_{\mu I}P^4 + 64T^3_{\mu I}P^3 + 32T^2_{\mu I}P^2 + 8T_{\mu I}(1-\tau_1)P}{8T_{\mu I}P[4T_{\mu I}P(2T^2_{\mu I}P^2 + 2T_{\mu I}P + 1) + 1] + 1}\overline{\varphi}_Y .$$

The introduction of one derivative allows us to exclude the velocity component of the error, ensuring the properties of a system with second-order astatism in control. Based on 4.9 when $\tau_1 = 1c$ the transfer function of an equivalent open-loop system can be obtained in the form:

$$W_э(P) = \frac{8T_{\mu I}P + 1}{32T^2_{\mu I}P^2(2T^2_{\mu I}P^2 + 2T_{\mu I}P + 1)} .$$

The corresponding AFC Lm [$W_2(jw)$] is shown in Fig. 3.7 (curve 2), and the response of the system to the control jump in Fig. 3.8 (curve 2).

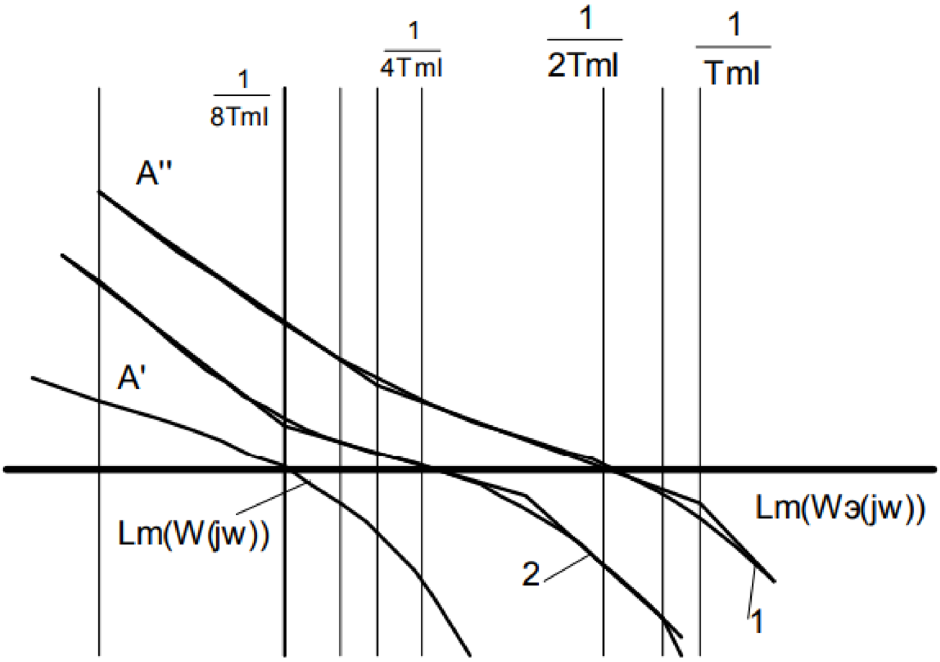


Fig. 3.7. - AFC of an equivalent open-loop system Lm [W $_{e2}$ (jw)]

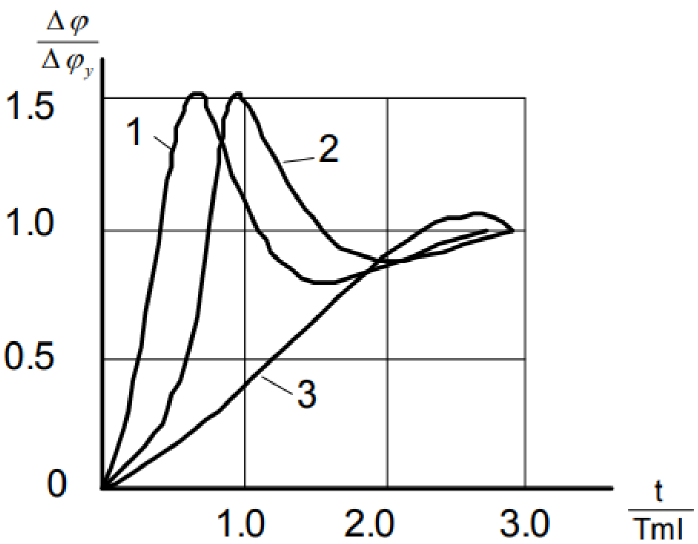


Fig. 3.8. - System Response to Control Racing

Chapter 4

Filtering Signals with Arduino

4.1 Measurement noise

Noise can be roughly divided into two types: constant sensor noise with the same deviation (Fig. 4.1), and random noise that occurs under variousrandom (most often external) circumstances (Fig. 4.2).

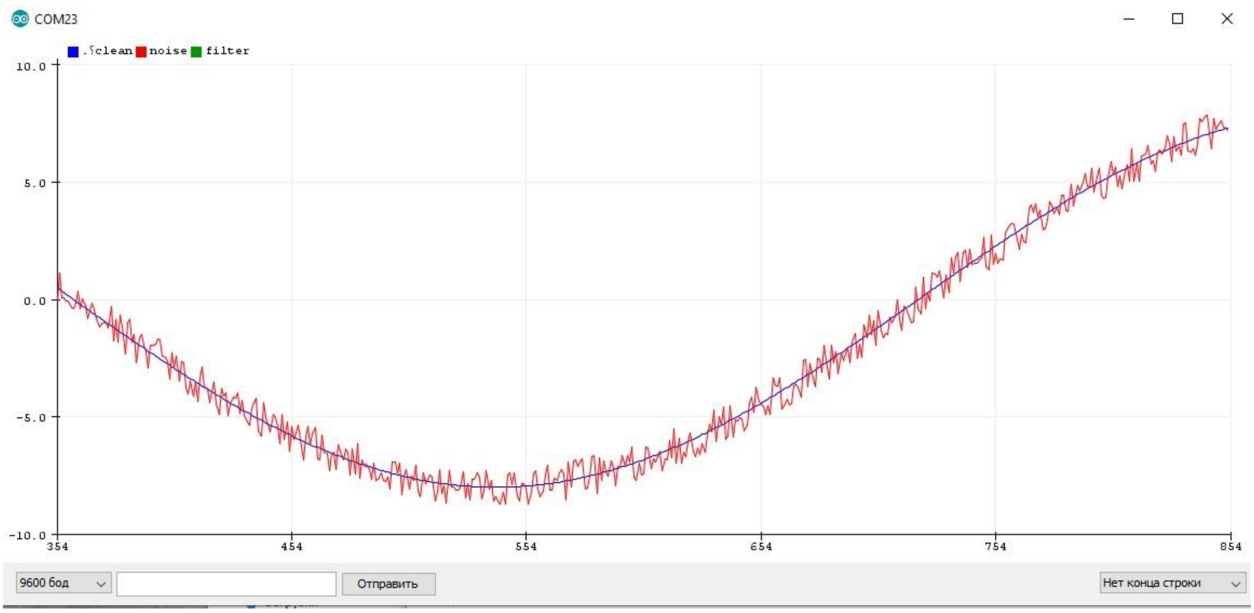


Fig. 4.1. sensor noise

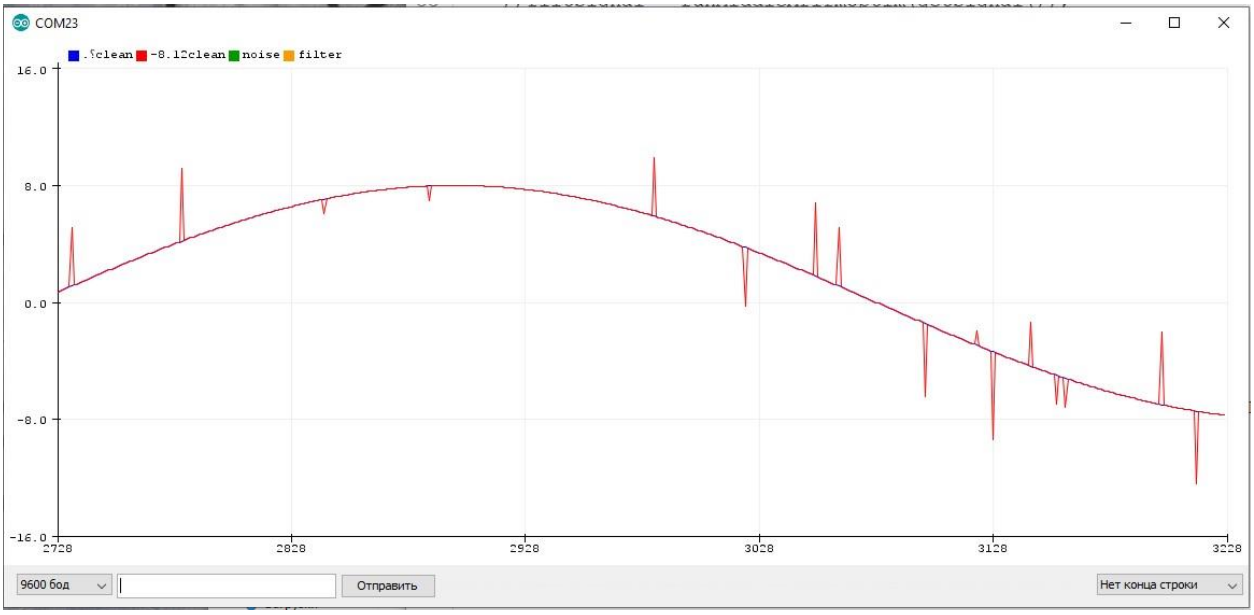


Fig. 4.2. random noise

A little noise is observed with any analog sensor, which is interrogated by means of the Arduino ADC. Moreover, the ADC itself practically does not make noise, if you provide high-quality power supply to the board and the absence of electromagnetic interference - the signal from the same potentiometer will be perfectly flat. But as soon as the power supply becomes of poor quality, for example, from a cheap power supply, the picture changes. Or, for example, without a load, the power supply provides good power and there is no noise, but as soon as the load appears, noises associated with the device of the power supply and the absence of normal output filters come out. Or another option - somewhere near the wire to the analog sensor, a powerful source of electromagnetic radiation (a wire with a large alternating current) appears, which induces an additional EMF in the wires and we again see noise. Yes, these reasons can be eliminated in hardware by adding power filters and shielding all analog wires, but this does not always work, and therefore in this lesson we will talk about software filtering of values.

4.2 Measuring values

Let's see how the signal is measured in a real device. Naturally, this does not happen every iteration of the loop, but for example, according to some kind of timer. Let's imagine that the blue graph reflects the real process, and the red one - the measured value with a certain period(Fig. 4.3).

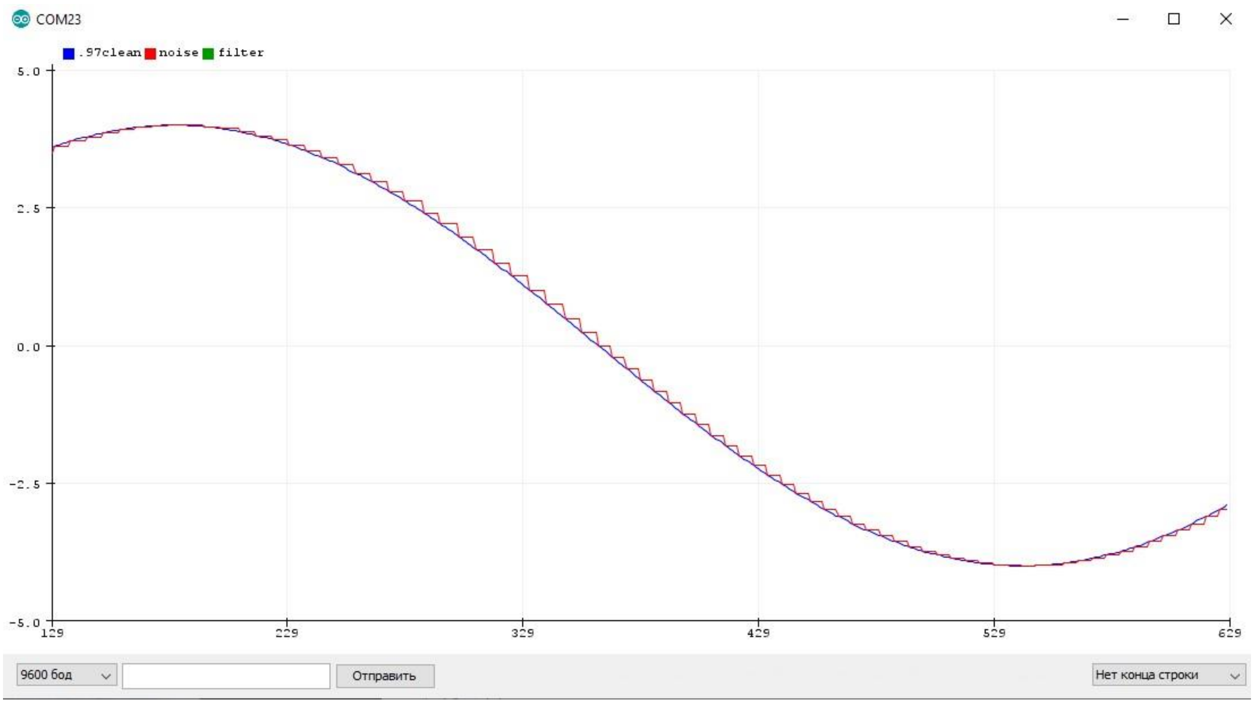


Fig. 4.3. Signal measuring in a real device

I think it is obvious that between the periods of measuring the value, the measured value does not change and remains constant, as can be seen from the graph. Let's lengthen the period and see how the values are measured(Fig. 4.4).

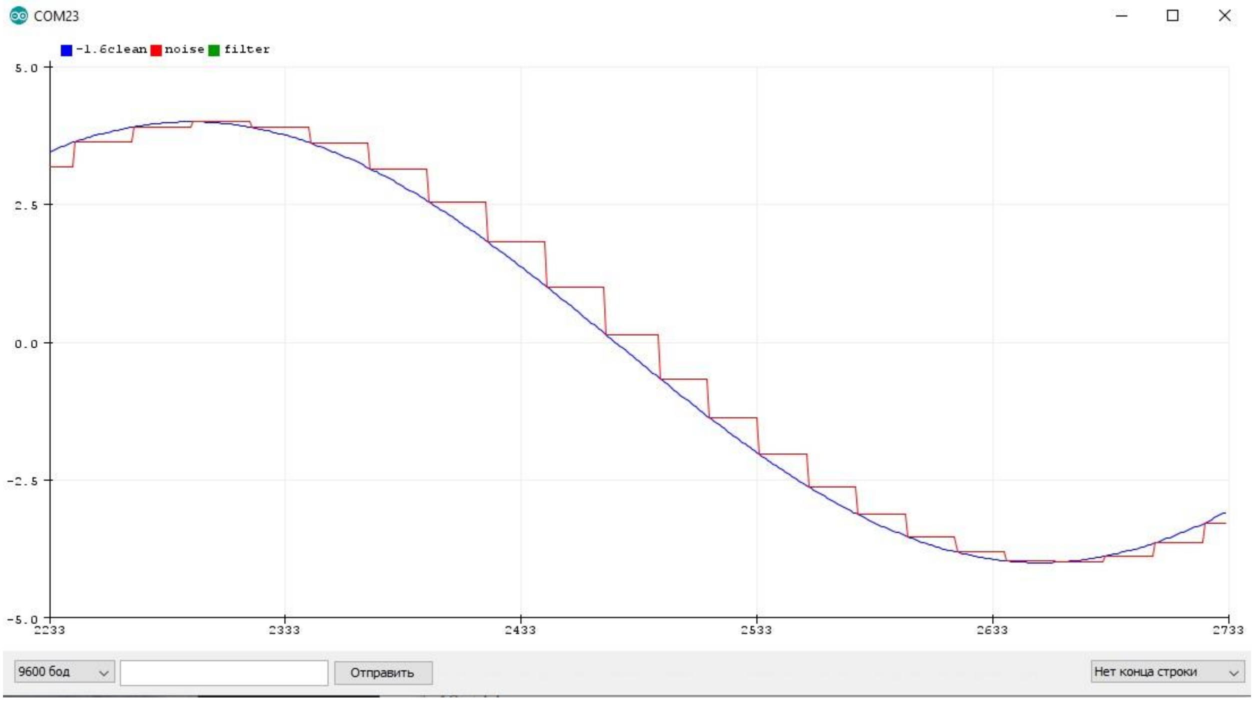


Fig. 4.4. Signal measuring in a real device with lengthen period

From this we can conclude that the faster the signal from the sensor changes, the more often it needs to be polled. But in general, everything depends on the goals that the program and the project as a whole should fulfill. This, in principle, is what signal processing is based on.

4.3 Filters

Digital (software) filters allow you to filter out various noise. Some popular filters will be shown in the following examples. All examples are designed as a filtering function, which is passed a new value as a parameter, and the function returns the filtered value. Some functions need additional settings, which are rendered as variables.

Important: almost every filter can be customized better than shown in the examples with graphs. In the examples, the filter is specially tuned not ideally so that it is possible to evaluate the peculiarity of the operation of the algorithm of each of the filters.

4.3.1 Average

Single sampling

The arithmetic mean is calculated as the sum of the values divided by their number(Fig. 4.5). The first algorithm works exactly like this: in a loop we sum everything into some variable, then divide by the number of measurements.

```
const int NUM_READ = 30;

float midArifm()
{
	float sum = 0;
	for (int i = 0; i < NUM_READ; i++)
		sum += значение
	return (sum / NUM_READ);
}

int midArifm() {
	long sum = 0;
	for (int i = 0; i < NUM_READ; i++)
		sum += значение;
	return ((float)sum / NUM_READ);
}
```

Features of use

- Perfectly averages noise of any nature and magnitude
- For integer values, it makes sense to take the number of measurements from powers of two (2, 4, 8, 16, 32 ...) then the compiler optimizes division into a shift, which is executed a hundred times faster. This is if you are completely chasing code execution optimization
- "Strength" of the filter is adjusted by the sample size (NUM_READS)
- Takes multiple measurements at once, which can be time-consuming!

- It is recommended to use it where the time of one measurement is negligible, or measurements are rarely done in principle.

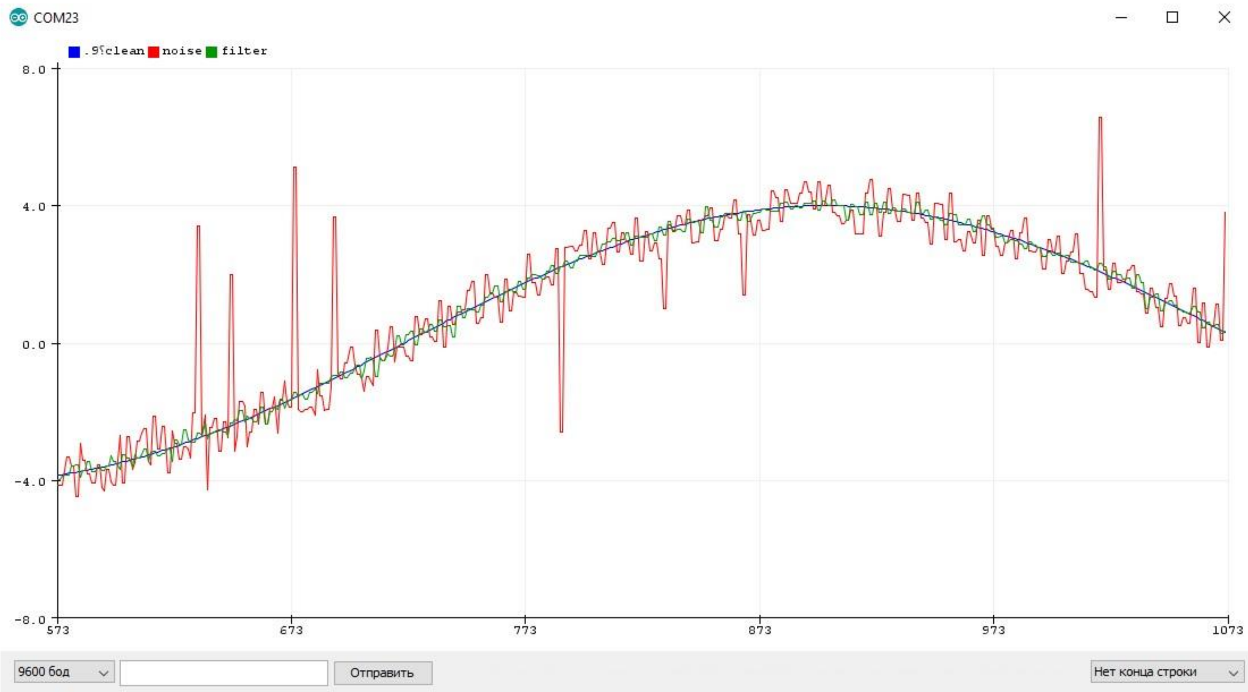


Fig. 4.5. Avarage

Stretched sample

It differs from the previous one in that it sums up several measurements, and only after that gives the result(Fig 4.6). Returns the previous result between calculations:

```
const int NUM_READ = 10;

float midArifm2(float newVal)
{
      static byte counter = 0;
      static float prevResult = 0;
      static float sum = 0;
      sum += newVal;
      counter++;
      if (counter == NUM_READ)
      {
            prevResult = sum / NUM_READ;
            sum = 0;
            counter = 0;
      }
      return prevResult;
}
```

Features of use

• Perfectly averages noise of any nature and magnitude

• "Strength" of the filter is adjusted by the sample size (NUM_READS)

• For integer values, it makes sense to take the number of measurements from powers of two (2, 4, 8, 16, 32 ...) then the compiler optimizes division into a shift, which is executed a hundred times faster. This is if you are completely chasing code execution optimization

• Takes only one measurement at a time, does not block the code for a long period

• It is recommended to use where the signal itself changes slowly, because due to the extended sampling time, the signal can have time to change

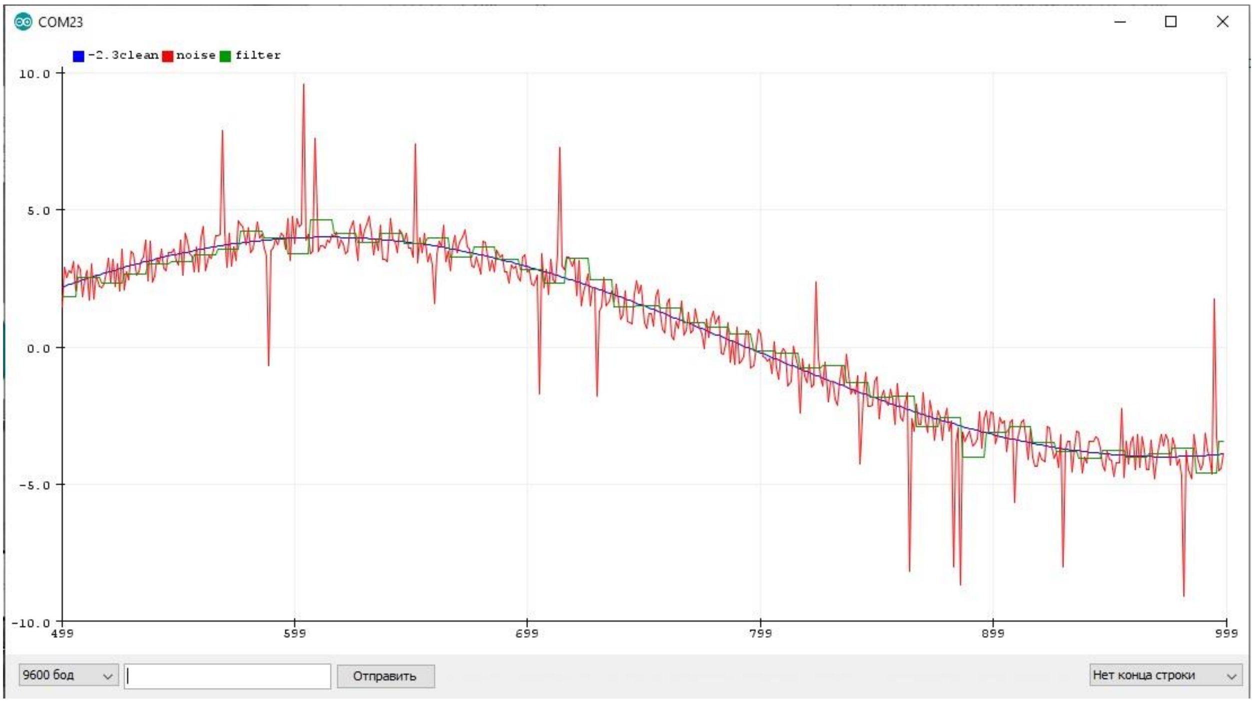


Fig. 4.6. Stretched sample

4.3.2 Running arithmetic mean

This algorithm works on the principle of a buffer, which stores the last few measurements for averaging. Each time the filter is called, the buffer is shifted, a new value is added to it and the oldest is removed, then the buffer is averaged over the arithmetic mean(Fig. 4.7). There are two variants of execution: clear and optimal:

```
const int NUM_READ = 10;

float runMiddleArifm(float newVal)
 {
	static byte idx = 0;
	static float valArray[NUM_READ];
	valArray[idx] = newVal;
	if (++idx >= NUM_READ) idx = 0;
	float average = 0;
	for (int i = 0; i < NUM_READ; i++)
	{
		average += valArray[i];
	}
	return (float)average / NUM_READ;
}

float runMiddleArifmOptim(float newVal)
{
	static int t = 0;
	static int vals[NUM_READ];
	static int average = 0;
	if (++t >= NUM_READ) t = 0;
	average -= vals[t];
	average += newVal;
	vals[t] = newVal;
	return ((float)average / NUM_READ);
}
```

Features of use

- Averages the last N measurements, due to which the value lags behind. Needs fine tuning of the polling rate and sample size

• For integer values, it makes sense to take the number of measurements from powers of two (2, 4, 8, 16, 32 ...) then the compiler optimizes division into a shift, which is executed a hundred times faster. This is if you are completely chasing code execution optimization

• "Strength" of the filter is adjusted by the sample size (NUM_READS)

• Takes only one measurement at a time, does not block the code for a long period

• I am showing this filter purely for information purposes, in real projects it is better to use a running average. About him below

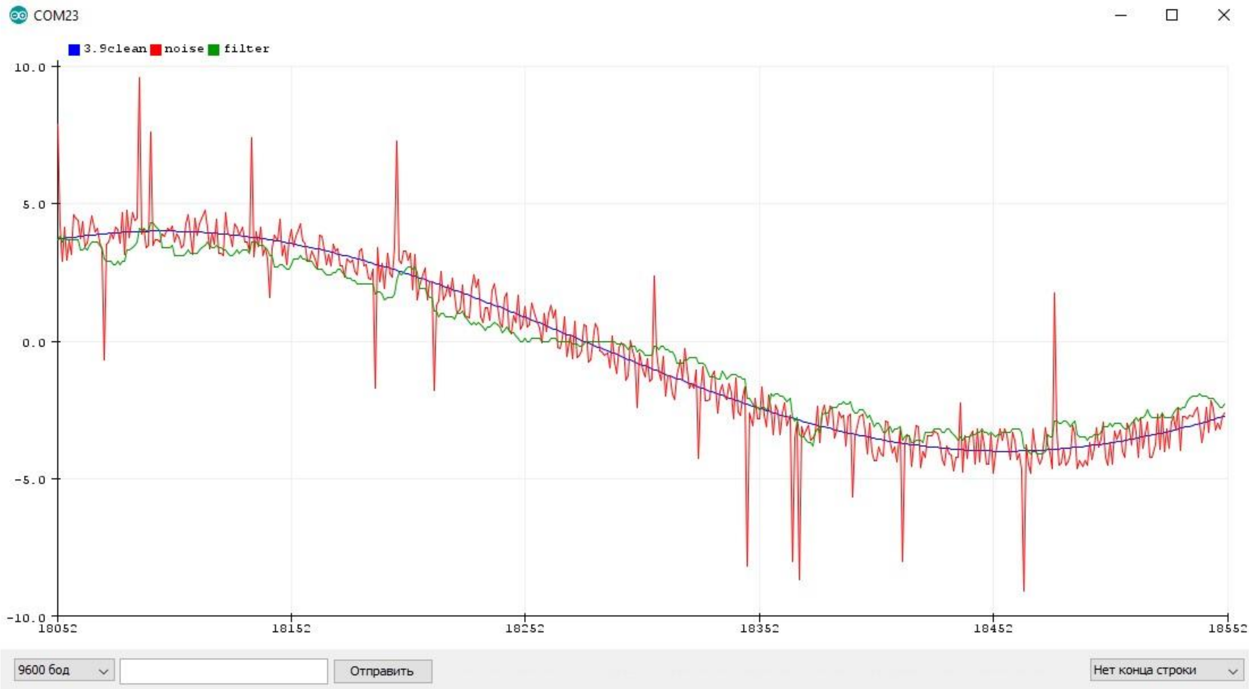


Fig. 4.7. Running arithmetic mean

4.3.3 Exponential running average

Running Average is the simplest and most effective filter of values, the effect is similar to the previous one, but much more optimal in terms of implementation:

```
float k = 0.1; // 0.0-1.0

float expRunningAverage(float newVal)
{
      static float filVal = 0;
      filVal += (newVal - filVal) * k;
      return filVal;
}
```

Features of use

- The lightest, fastest and easiest algorithm to calculate! At the same time, very effective
- "Strength" of the filter is adjusted by a factor (0.0 - 1.0). The smaller it is, the smoother the filter.
- Takes only one measurement at a time, does not block the code for a long period
- The more often measurements, the better it works
- At small values of the coefficient, it works very smoothly, which can also be used for your own purposes

This is how a running average deals with an evenly growing signal + random outliers. Blue graph - real value, red - filtered with a factor of 0.1, green - a factor of 0.5(Fig. 4.8) (Fig. 4.9) (Fig. 4.10).

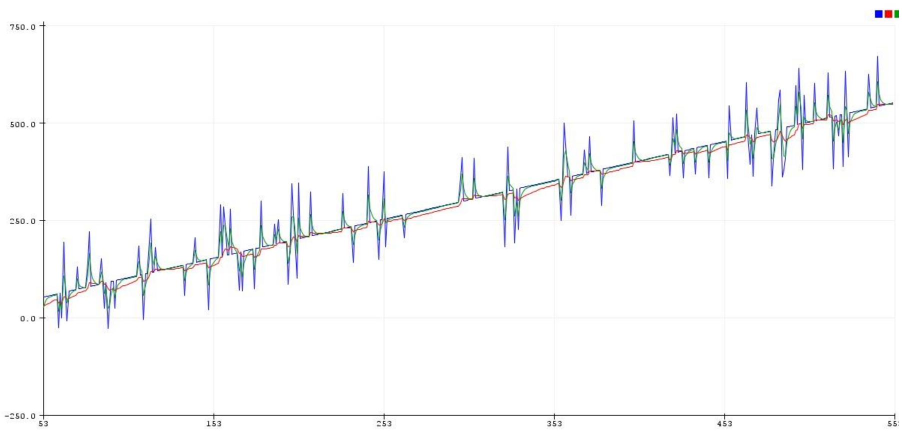


Fig. 4.8. Example of a noisy sine

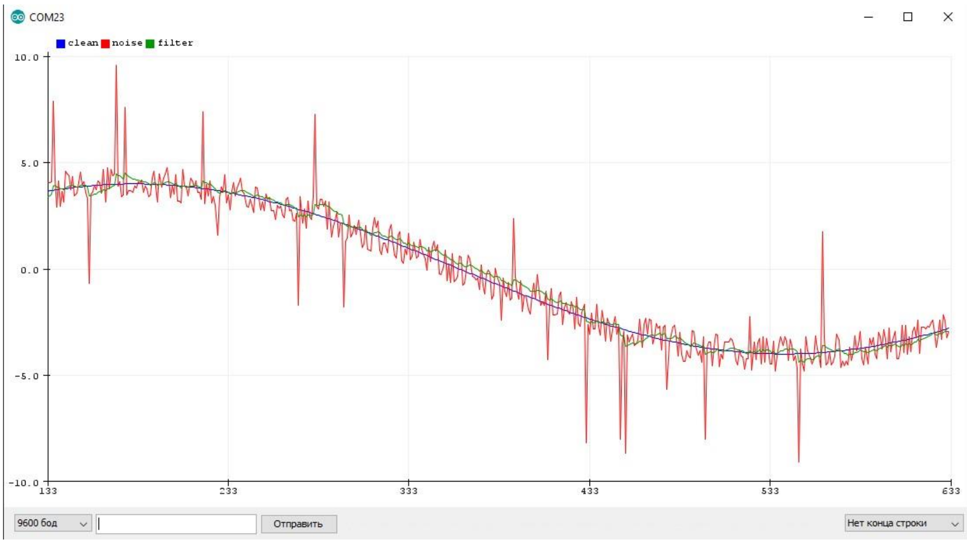


Fig. 4.9. Example with a noisy square signal showing filter lag

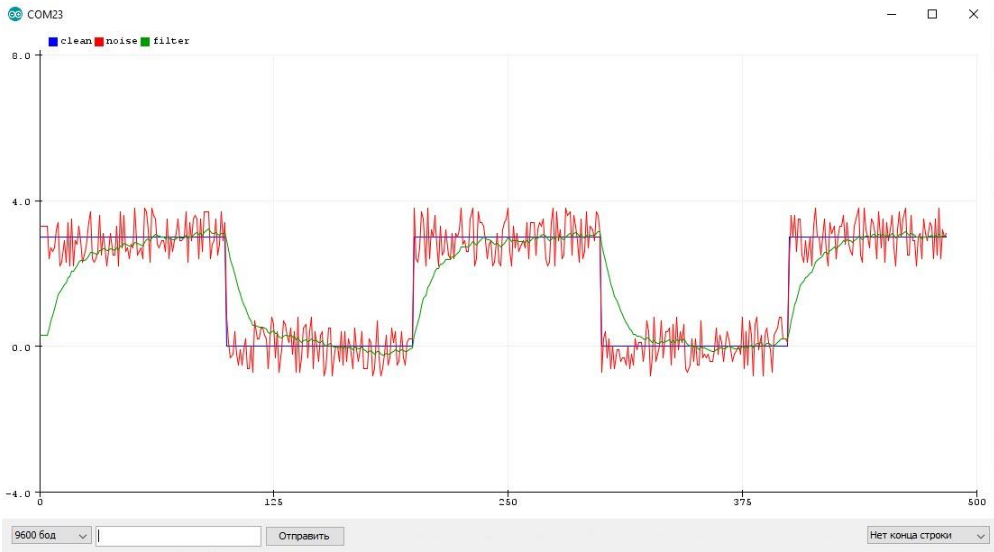


Fig. 4.10. Example with a step signal

4.3.4 Adaptive factor

For the running average to work correctly with sharply changing signals, the coefficient can be made adaptive so that it adapts to abrupt changes in the value, for example, if the filtered value is “far” from the real one, the coefficient increases sharply, allowing you to quickly close the “gap” between the values(Fig. 4.11). If the value is “close”, the coefficient is set small in order to filter the noise well:

```
float expRunningAverageAdaptive(float newVal)
{
      static float filVal = 0;
      float k;

      if (abs(newVal - filVal) > 1.5) k = 0.9;
      else k = 0.03;
      filVal += (newVal - filVal) * k;
      return filVal;
}
```

Thus, even the simplest filter can be "programmed" and made smarter. This is the beauty of programming!

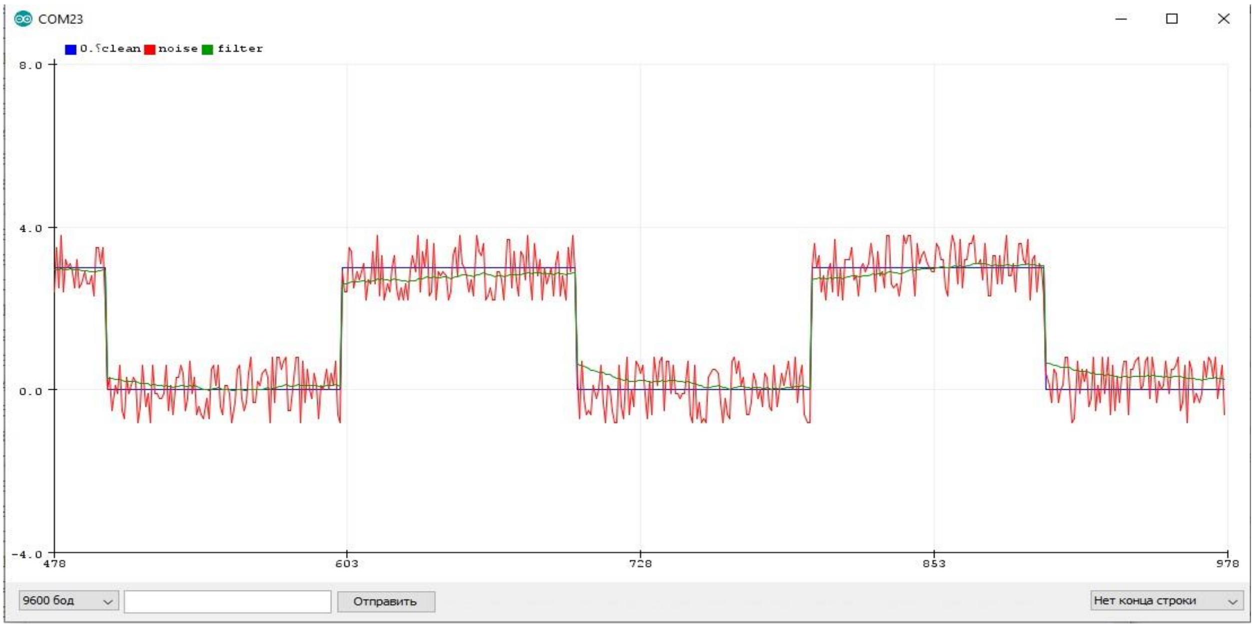


Fig. 4.11. Adaptive factor

4.3.5 A simple example

I will show a separate simple example of the real work of the filter, the running average, as the most frequently used one. The rest of the filters are by analogy. We will filter the signal from the analog pin A0:

```
void setup() {
Serial.begin(9600);
Serial.println("raw , filter");
}
float filteredVal = 0;
void loop() {
int newVal = analogRead(0);
filteredVal += (newVal - filteredVal) * 0.1;
Serial.print(newVal);
Serial.print(',');
Serial.println(filteredVal);
delay(10);
}
```

The code outputs a real and filtered value to the port. You can connect a potentiometer to A0 and turn it while watching the graph.

4.3.6 Median filter

The median filter also finds the average value, but not by averaging, but by choosing it from the presented ones. The algorithm for the 3rd order median (selection from three values) looks like this:

```
float middle;
if ((a <= b) && (a <= c)) {
middle = (b <= c) ? b : c;
} else {
if ((b <= a) && (b <= c)) {
middle = (a <= c) ? a : c;
} else {
middle = (a <= b) ? a : b;
}
}
```

For ease of use, you can make a function that will store a buffer for the last three values and automatically add new ones to it:

```
float median(float newVal) {
static float buf[3];
static byte count = 0;
buf[count] = newVal;
if (++count >= 3) count = 0;
float a = buf[0];
float b = buf[1];
```

```
float c = buf[2];
float middle;
if ((a <= b) && (a <= c)) {
middle = (b <= c) ? b : c;
} else {
if ((b <= a) && (b <= c)) {
middle = (a <= c) ? a : c;
}
else {
middle = (a <= b) ? a : b;
}
}
return middle;
}
```

The median for a larger window of values is described by a very impressive algorithm(Fig. 4.12)(Fig. 4.13)

Features of use

- Median perfectly filters sudden changes in value
- Takes only one measurement at a time, does not block the code for a long period
- Algorithm “more than three” is very cumbersome
- Lagging by half the filter dimension

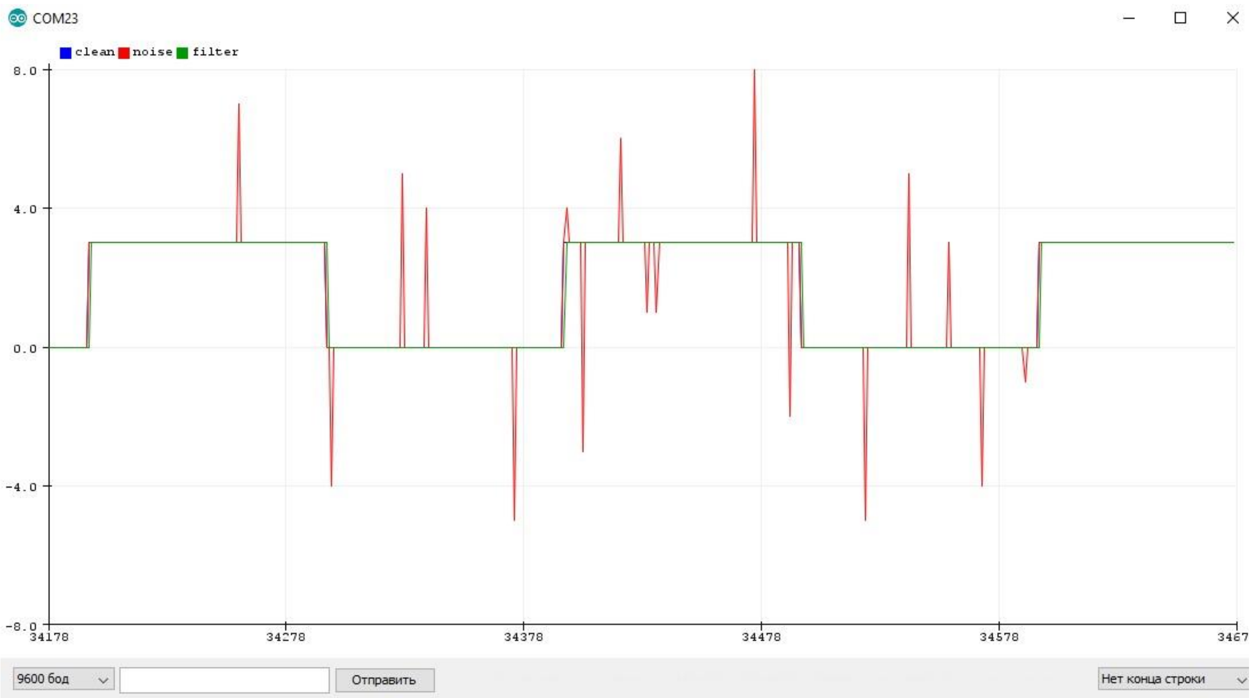


Fig. 4.12. Median filter with a step signal

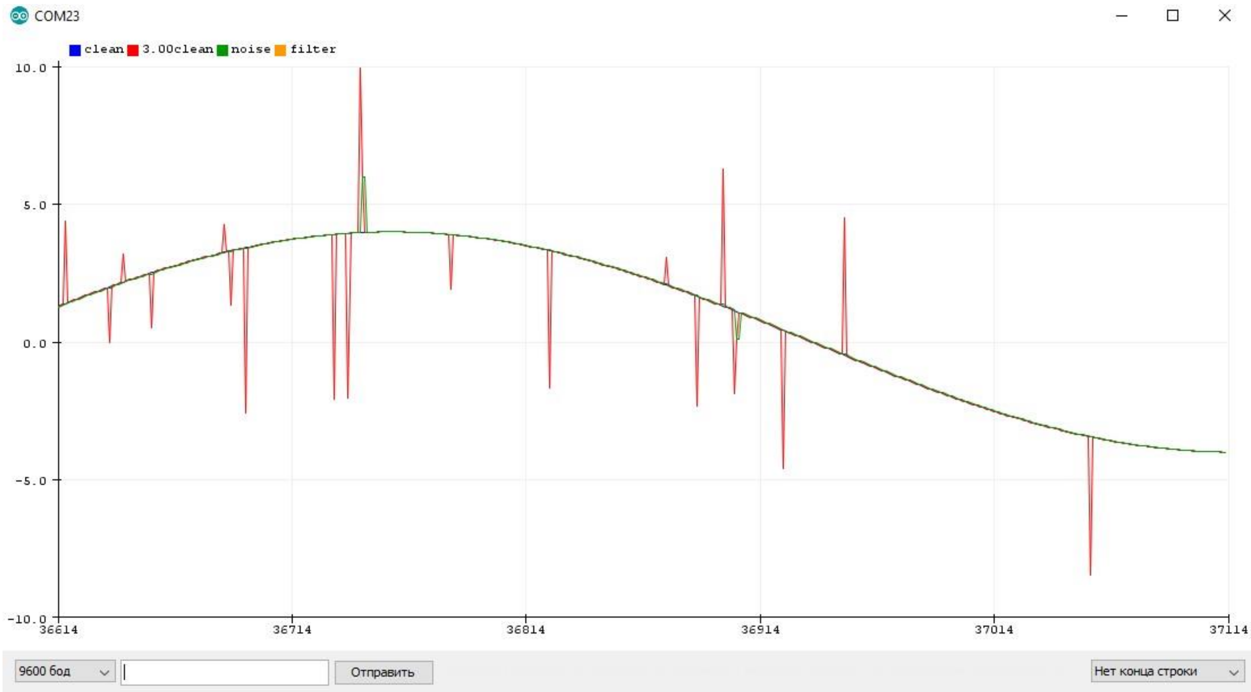


Fig. 4.13. Median filter

4.3.7 Simple Kalman

I found this algorithm on the Internet, I lost the source. The filter adjusts the measurement spread (expected measurement noise), the estimation spread (it adjusts itself during the filter operation, you can set the same as the measurement spread), the rate of change of values (0.001-1, vary yourself).

```
float _err_measure = 0.8;
float _q = 0.1;
float simpleKalman(float newVal) {
float _kalman_gain, _current_estimate;
static float _err_estimate = _err_measure;
static float _last_estimate;
_kalman_gain = (float)_err_estimate / (_err_estimate
+ _err_measure);
_current_estimate = _last_estimate +
(float)_kalman_gain * (newVal - _last_estimate);
_err_estimate = (1.0 - _kalman_gain) * _err_estimate
+ fabs(_last_estimate - _current_estimate) * _q;
_last_estimate = _current_estimate;
return _current_estimate;
}
```

Features of use

• It filters well both constant noise and harsh emissions

• Takes only one measurement at a time, does not block the code for a long period

• Slightly lagging, like a running average

• Adjusts in the course of work

• The more often measurements, the better it works

• The algorithm is very difficult, the calculation takes ~ 90 µs at a system frequency of 16 MHz

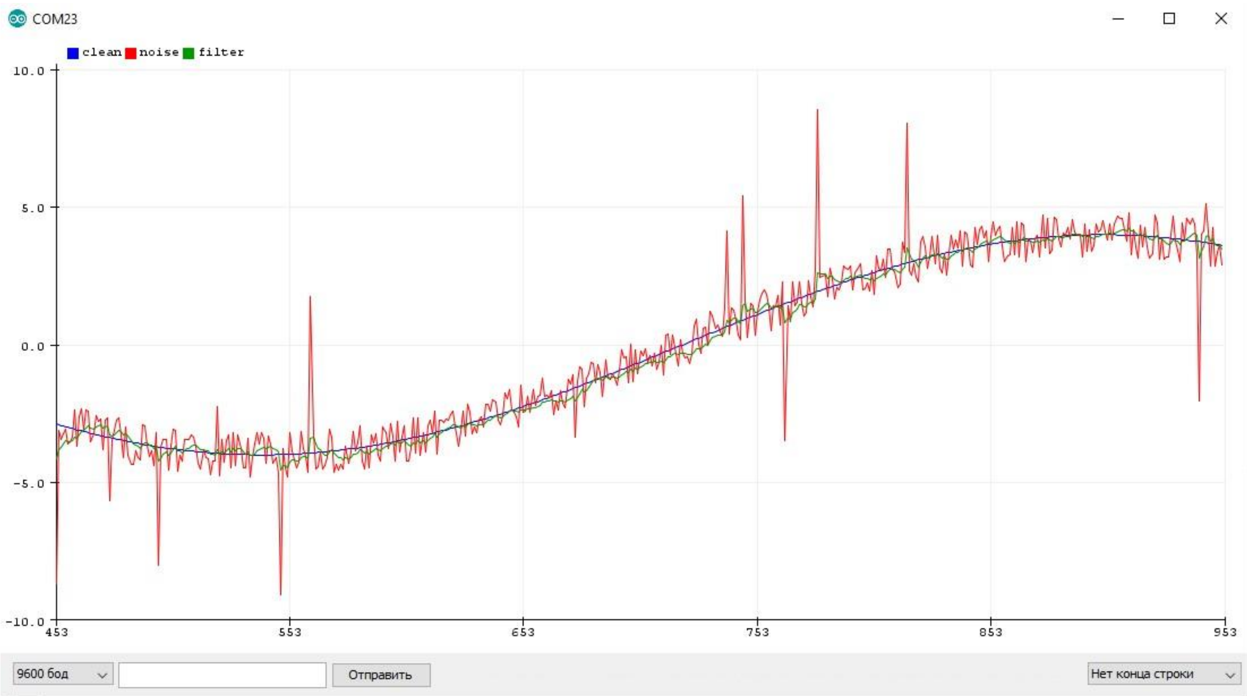


Fig. 4.14. Simple Kalman filter

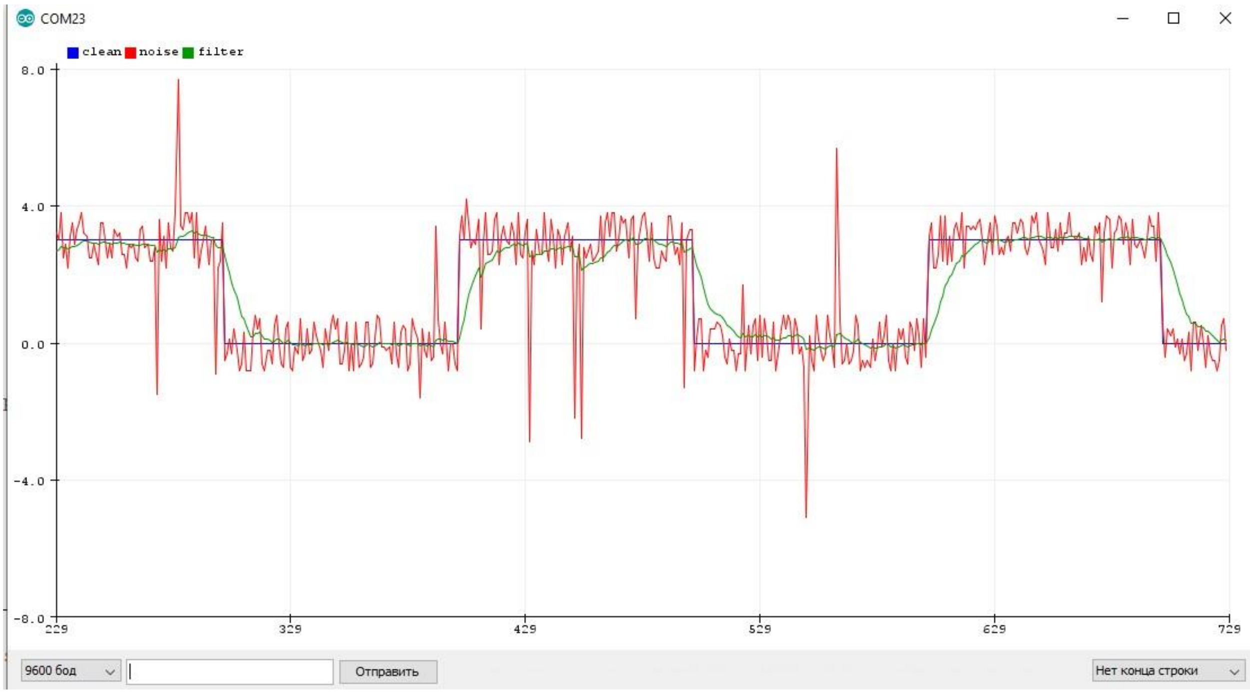


Fig. 4.15. Simple Kalman filter with a step signal

4.3.8 Alpha Beta filter

AB filter is also a type of Kalman filter(Fig. 4.16)

```
float dt = 0.02;
float sigma_process = 3.0;
float sigma_noise = 0.7;
float ABfilter(float newVal) {
static float xk_1, vk_1, a, b;
static float xk, vk, rk;
static float xm;
float lambda = (float)sigma_process * dt * dt /
sigma_noise;
float r = (4 + lambda - (float)sqrt(8 * lambda +
lambda * lambda)) / 4;
a = (float)1 - r * r;
b = (float)2 * (2 - a) - 4 * (float)sqrt(1 - a);
xm = newVal;
xk = xk_1 + ((float) vk_1 * dt );
vk = vk_1;
rk = xm - xk;
xk += (float)a * rk;
vk += (float)( b * rk ) / dt;
```

```
xk_1 = xk;
vk_1 = vk;
return xk_1;
}
```

Features of use

• Good filter if set up correctly

• But very hard!

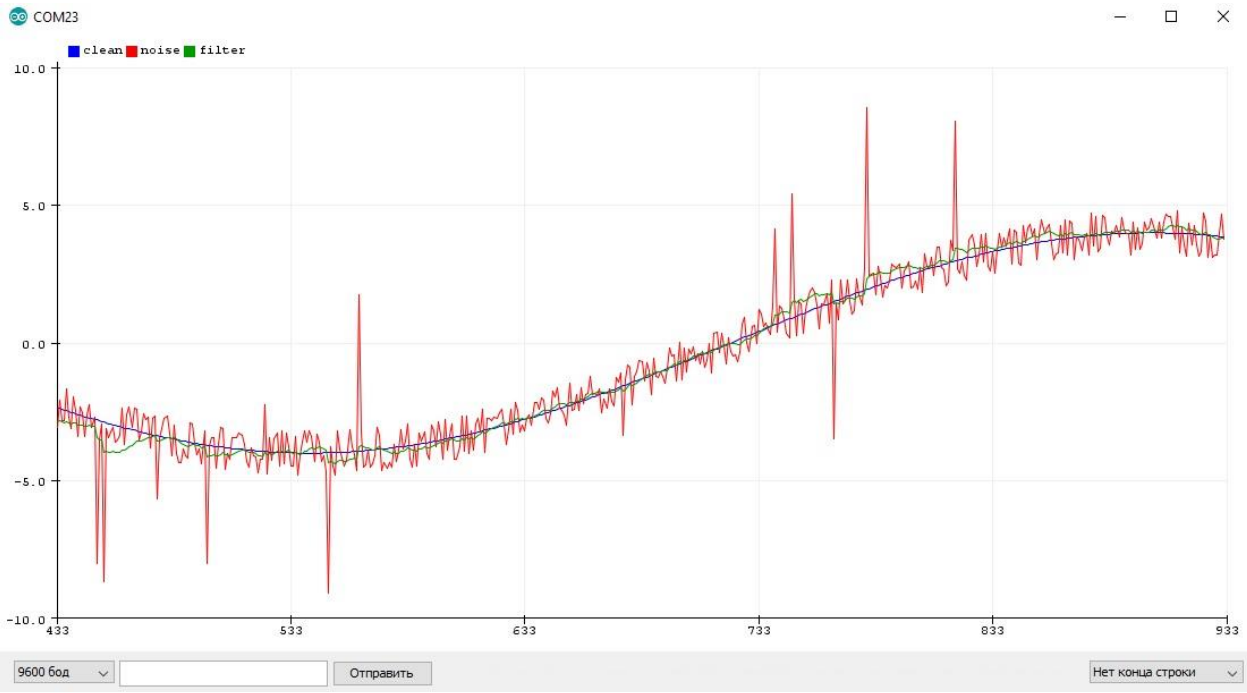


Fig. 4.16. Alpha Beta filter

4.3.9 Least square method

The next filter allows you to observe a noisy process and predict its behavior, it is called the method of least squares. A purely graphical explanation here is this: we have a dataset in the form of several points. We see that the general direction is to increase, but the noise does not allow us to make an accurate conclusion or forecast. Suppose there is a line, the sum of the squares of the distances from each point to which is the minimum. Such a line will most accurately represent the real change among the noisy value. In some article I found an algorithm that allows you to find the parameters of this line, again ported it to C ++ and is ready to show you. This algorithm produces the parameters of a straight line that is equidistant from all points.

```
float a, b, delta;
void minQuad(int *x_array, int *y_array, int arrSize)
{
int32_t sumX = 0, sumY = 0, sumX2 = 0, sumXY = 0;
arrSize /= sizeof(int);
for (int i = 0; i < arrSize; i++) {
sumX += x_array[i];
sumY += (long)y_array[i];
sumX2 += x_array[i] * x_array[i];
sumXY += (long)y_array[i] * x_array[i];
}
a = (long)arrSize * sumXY;
a = a - (long)sumX * sumY;
a = (float)a / (arrSize * sumX2 - sumX * sumX);
b = (float)(sumY - (float)a * sumX) / arrSize;
delta = a * (x_array[arrSize-1] - x_array[0]);
```

Features of use

- In my implementation, it takes two arrays and calculates the parameters of a line equidistant from all points

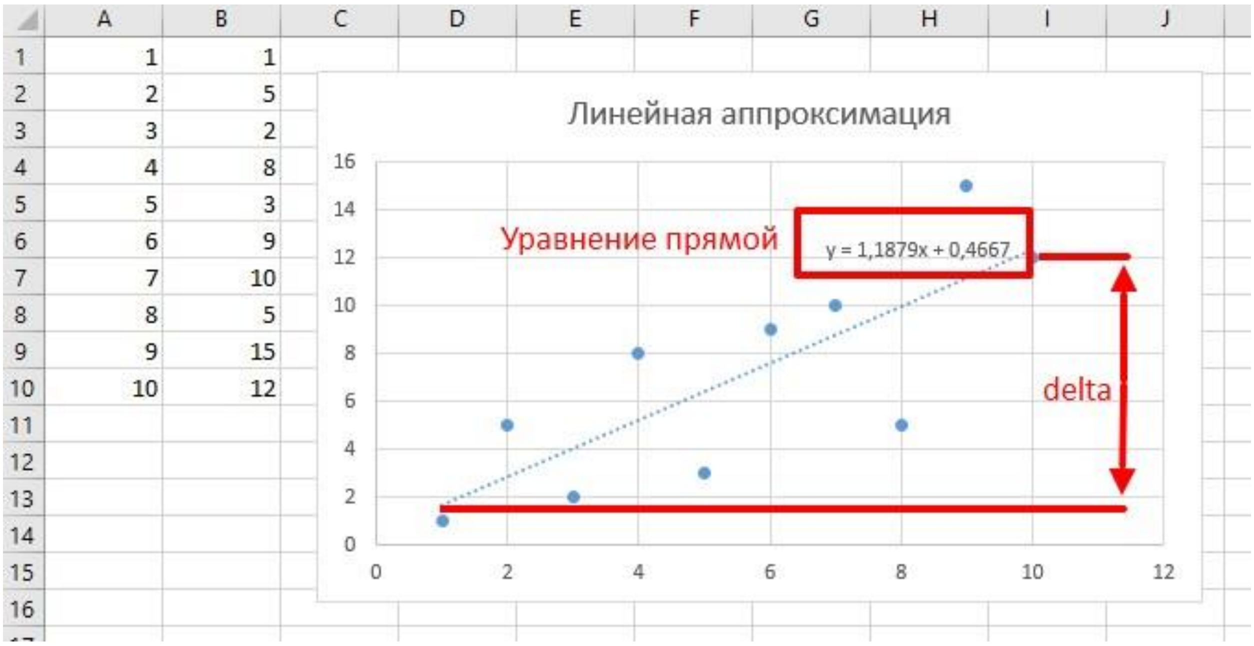


Fig. 4.17. Least square method in excel

4.3.10 Fast integer filters

All the filters discussed above cannot boast of a high speed of calculations: a bunch of additions, division, working with floats, and so on. Sometimes it is necessary to filter out as quickly as possible, for example, an integer signal from an ADC, and this is where smart integer filters come to the rescue. Due to integer calculations, the filters have a slight deviation from the real signal (see graphs below).

<u>First(Fig. 4.18)</u>

filt = (filt >> 1) + (signal >> 1);

The filter has no settings, consists of addition and two shifts, is executed instantly. But it also filters quite a bit:

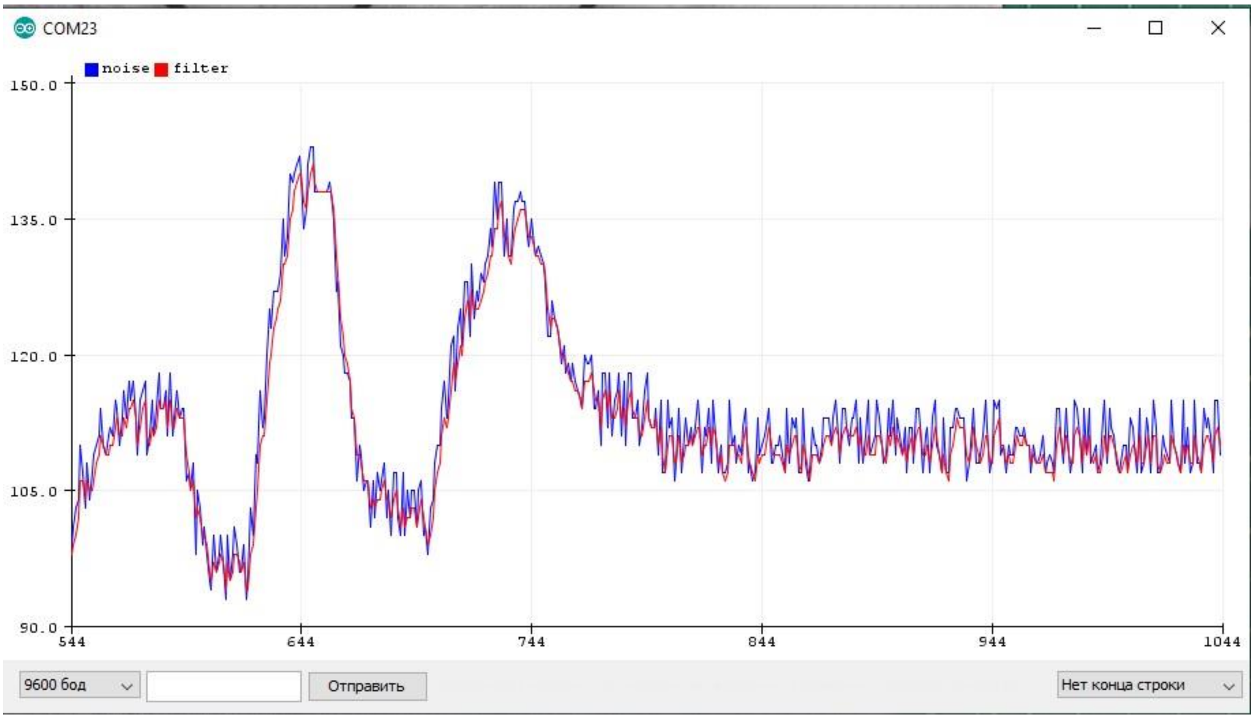


Fig. 4.18. First fast integer filter

<u>Second(Fig. 4.19)</u>

filt = (A * filt + B * signal) >> k;

The coefficients for this filter are selected as follows:

- **k** = 1, 2, 3…
- **A** + **B** = 2^**k**

• The larger the A, the smoother the filter (A / B ratio)

• The larger the k, the smoother the filter can be made. But more than 5 no longer makes sense, because A = 31, B = 1 is already very smooth, and int may overflow when increasing.

• The result of multiplication must not exceed int, otherwise you will have to convert to long

• For more information about the choice of coefficients, read the article, link above.

For example, k = 4, so A + B = 16. We want a smooth filter, we take A = 14, B = 16: filt = (14 * filt + 2 * signal) >> 4;

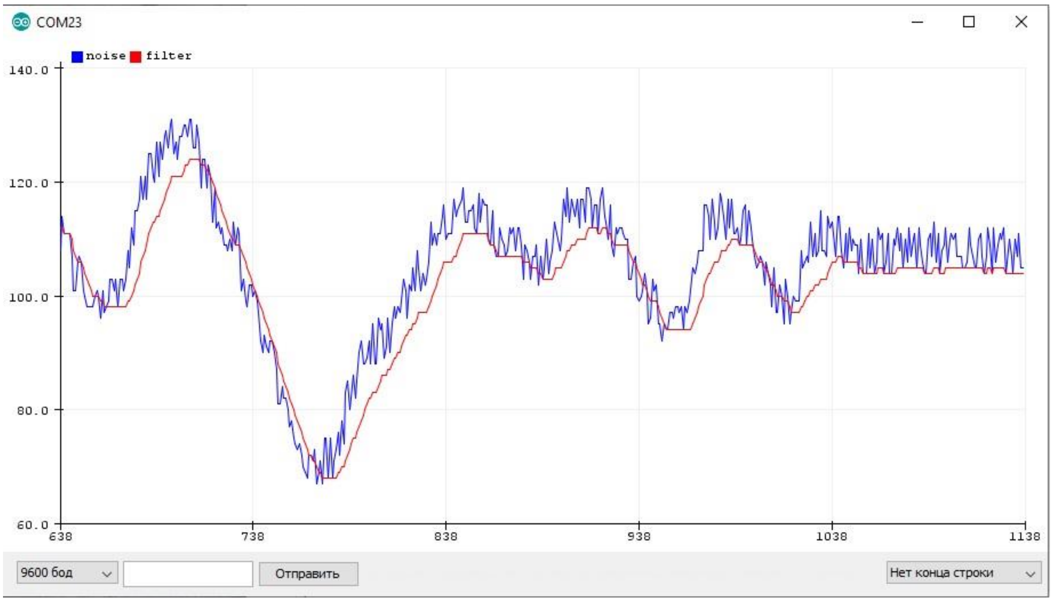


Fig. 4.19. Second fast integer filter

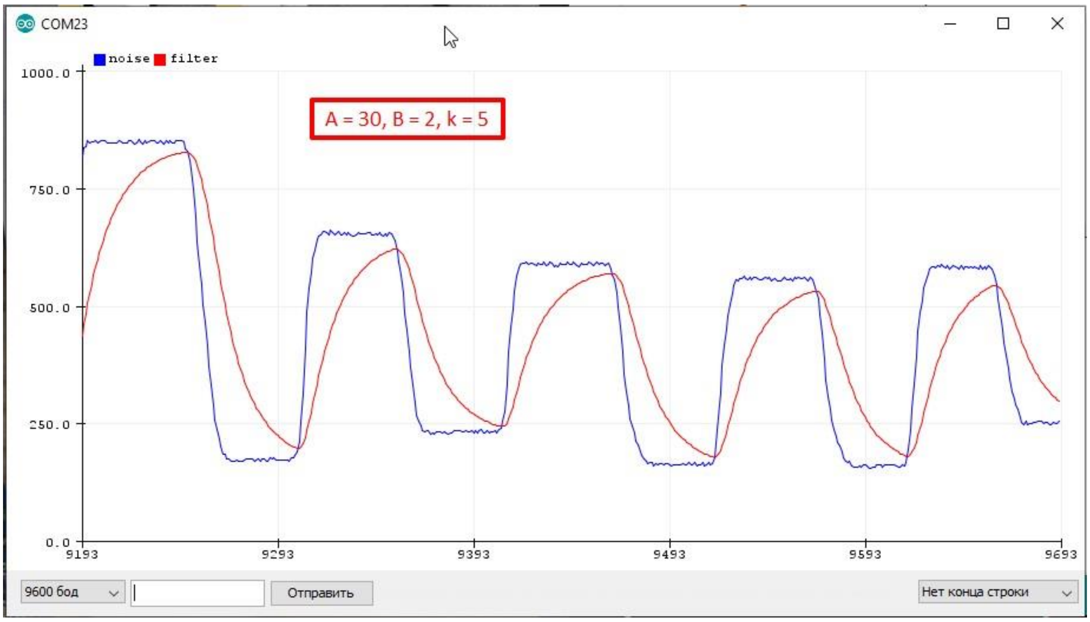


Fig. 4.20

Third(Fig. 4.21)

The third algorithm follows from the second: we take the coefficient B equal to 1 and save one multiplication:

filt = (A * filt + signal) >> k;

Then the coefficients are chosen as follows:

- **k** = 1, 2, 3…
- **A** = (2^**k**) – 1
- k=2 A=3, k=3 A=7, k=4 A=15, k=5 A=31…
- The larger k, the smoother the filter

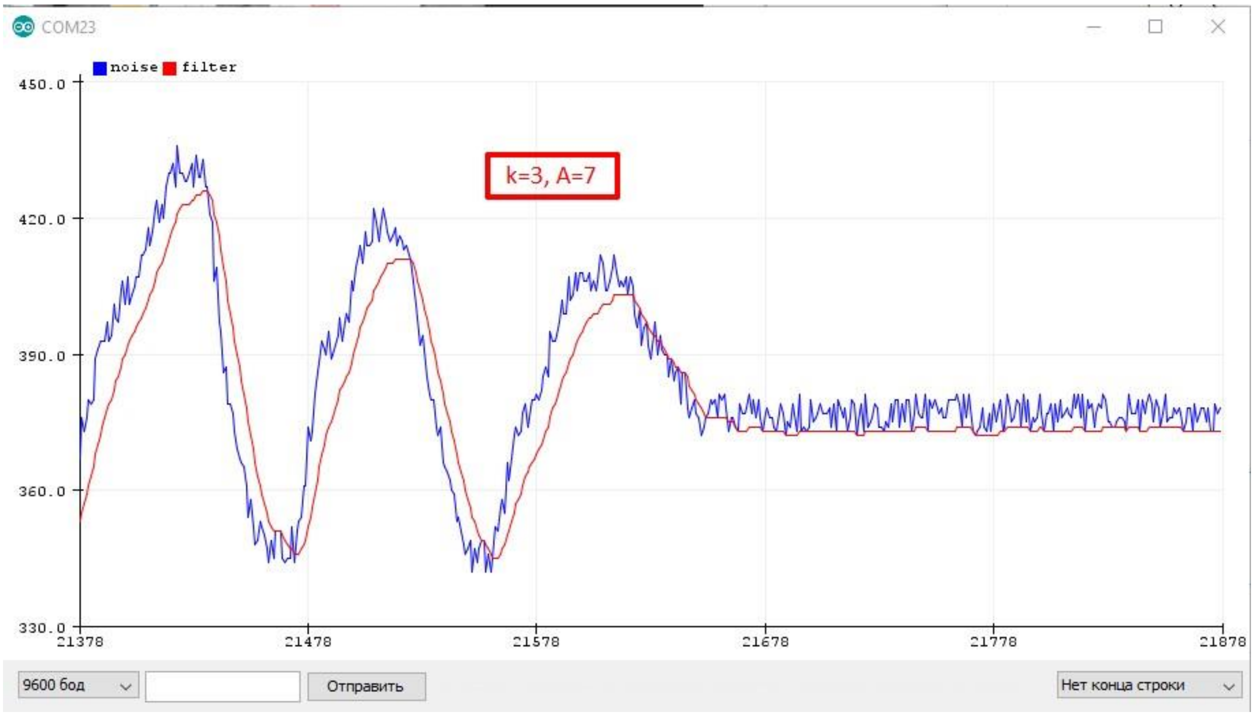


Fig. 4.21. Third fast integer filter

4.3.11 Which filter should you choose?

The median of the 3rd order + running average works very well, a smoothed signal with filtered outliers is obtained (first filtered by the median, then by the running average). AB filter and Kalman filter are excellent filters, they cope with a noisy signal no worse than a combination of median + running average, but they need fine tuning, and they are also quite cumbersome in terms of code. Linear approximation is a special-purpose tool that allows literally predicting the behavior of a value over a period - after all, we get the equation of a straight line. If you need maximum performance, we work only with integers and use integer filters. The median of the 3rd order + running average works very well, a smoothed signal with filtered outliers is obtained (first filtered by the median, then by the running average). AB filter and Kalman filter are excellent filters, they cope with a noisy signal no worse than a combination of median + running average, but they need fine tuning, and they are also quite cumbersome in terms of code. Linear approximation is a special-purpose tool that allows literally predicting the behavior of a value over a period - after all, we get the equation of a straight line. If you need maximum performance, we work only with integers and use integer filters.

Chapter 5

The list and the description of electronics for assembly of a bionic hand

- The microcontroller (I use Arduino Nano)
- Power supply 12V 2A
- The expansion card Nano Shield for Arduino Nano
- Servo actuator Futaba S3003 (5 pieces)
- EMG sensor

5.1 Arduino Nano

5.1.1 What is the microcontroller?

The microcontroller (fig 5.1) - the computer on one chip. It is intended for control of different electronic devices and implementation of interaction between them according to the program put in the microcontroller. Unlike the microprocessors used in personal computers, microcontrollers contain the built-in additional devices. These devices carry out the tasks under control of a microprocessor kernel of the microcontroller.

Fig. 5.1. Microcontroller

Devices of memory and input/output ports (I/O), interfaces of communication, timers, system hours belong to the most widespread built-in devices. Devices of memory include random access memory (RAM), read-only memories (ROM) reprogrammed by ROM (EPROM), electrically reprogrammable ROM (EEPROM). Timers include both real time clock, and timers of interruptions. Means of I/O include serial ports of communication, parallel ports (I/O of the line), analog-to-digital converters (A/D), digital/analog transformers (D/A), drivers of the LCD display (LCD) or drivers of the vacuum fluorescent display (VFD). The built-in devices have the increased reliability as they do not demand any external electrical circuits.

Unlike the microcontroller the controller usually call the payment constructed on the basis of the microcontroller, but rather often when using the concept "microcontroller" apply the reduced name of this device, discarding a prefix "micro" for simplicity. Also at the mention of microcontrollers it is possible to meet the words "chip" or "microchip", "crystal" (the majority of microcontrollers make on a uniform crystal of silicon), reductions of MK or from the English microcontroller - MC.

Microcontrollers can be met in a huge number of modern industrial and household appliances: machines, cars, phones, TVs, refrigerators, washing machines... and even coffee makers. Among vendors of microcontrollers it is possible to call Intel, Motorola, Hitachi, Microchip, Atmel, Philips, Texas Instruments, Infineon Technologies (which was Siemens Semiconductor Group) and many others.

The main classification sign of microcontrollers is digit capacity of the data processed by the arithmetic and logic unit (ALU). On this sign they are divided into 4-, 8-, 16-, 32-and 64-bit. Today the greatest share of the world market of microcontrollers belongs to eight-bit devices (about 50% in value terms). They are followed 16-bit also by the DSP microcontrollers (DSP - Digital Signal Processor - the digital signal processor) oriented to use in processing systems of signals (each of groups occupies approximately 20% of the market). In each group microcontrollers are divided into CISC-and RISC devices. The most numerous group are CISC microcontrollers, but in recent years among new chips the explicit trend of growth of a share of RISC architecture was outlined.

The clock rate, or, more precisely, bus speed, defines how many calculations can be executed for unit of time. Generally the capacity of the microcontroller and the power consumed by it increase with increase in clock rate. Capacity of the microcontroller is measured in MIPS (Million Instructions per Second - one million instructions per second). [12]

5.1.2 General information

Arduino Nano is the full-function miniature device on the basis of the ATmega328 microcontroller (Arduino Nano 3.0) or ATmega168 (Arduino Nano 2.x) adapted for use with prototyping boards. On functionality the device is similar to Arduino Duemilanove, and differs from it in the sizes, lack of the power connector and also other type (Mini-B) of an USB cable. Arduino Nano is developed and is issued Gravitech.[13]

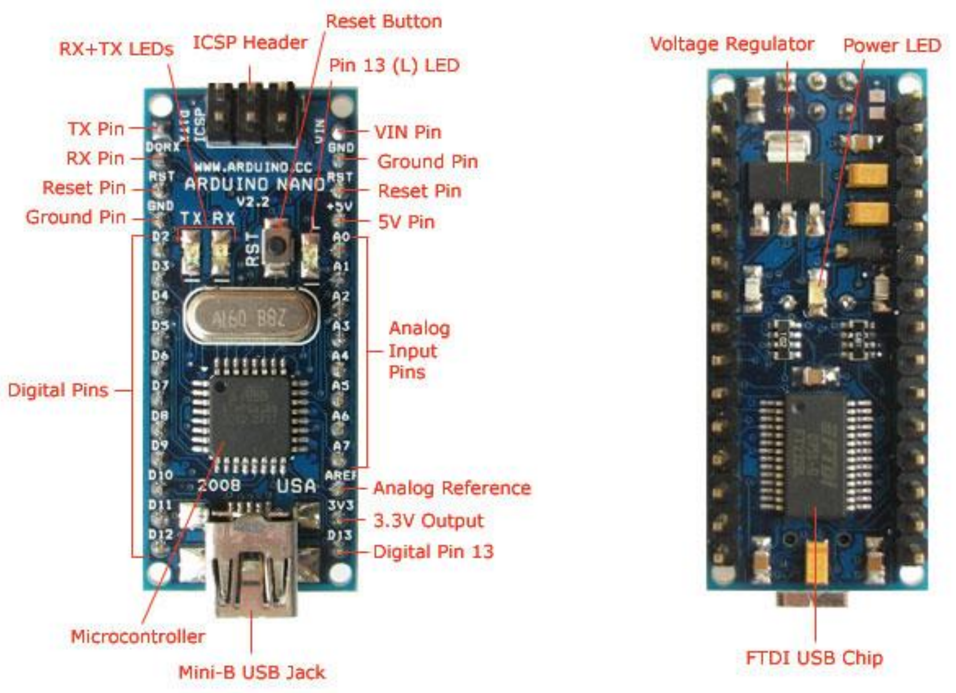


Fig 5.2. Microcontroller Arduino

5.1.3 Characteristics

Microcontroller	Atmel ATmega168 or ATmega328
Operating voltage (logic level)	5B
The supply voltage (recommended)	7-12B
Supply voltage (limit)	6-20B
Digital inputs and outputs	14 (from which 6 can be used as a PWM outputs)
Analog inputs	8
Maximum current of one output	40 mA
Flash-memory	16 CBs (ATmega168) or 32 CBs (ATmega328) from which 2 CBs are used by the loader
SRAM	1 CB (ATmega168) or 2 CBs (ATmega328)
EEPROM	512 bytes (ATmega168) or 1 CB (ATmega328)
Clock rate	16 MHz
Amount of a payment	1.85 cm x 4.3 cm

5.1.4 Power supply

Arduino Nano can be powered through the Mini-B USB cable, from the external power source with not with a stabilized voltage of 6-20B (through an output 30) or with the stabilized voltage of 5B (through an output 27). The device automatically selects the power source with the largest tension.

Tension on a chip of FTDI FT232RL moves only in case of a power supply of Arduino Nano through USB. Therefore at a power supply of the device from other external sources (not USB), the output 3.3B (FTDI created by a chip) will be inactive therefore LEDs of RX and TX can flicker in the presence of the high level of a signal on outputs 0 and 1.

5.1.5 Memory

The memory size of programs of the ATmega168 microcontroller is 16 CBs (from them 2 CBs are used by the loader); in ATmega328 - this volume is 32 CBs (from which 2 CBs are taken also away under the loader). In addition, ATmega168 has 1 CB of random access memory of SRAM and 512 bytes of EEPROM (with which for interaction the EEPROM library serves); and the ATmega328 microcontroller - 2 CBs SRAM and 1 CB EEPROM.

5.1.6 Inputs and outputs

With use of functions pinMode (), digitalWrite () and digitalRead () each of 14 digital outputs of Arduino Nano can work as an input or an output. The operating voltage of outputs - 5B. The maximum current which can give or consume one output makes 40 mA. All outputs are accompanied by the internal tightening resistors (by default disconnected) of 20-50 kOhm. In addition to the main, some outputs of Arduino can perform additional functions:

- **Serial interface: outputs 0 (RX) and 1 (TX).** Are used for receiving (RX) and transfer (TX) of data on the serial interface. These outputs are connected to the corresponding outputs of a chip transformer of USB-UART from FTDI.
- **External interruptions: outputs 2 and 3.** These outputs can be configured as sources of the interruptions arising under different conditions: at the low level of a signal, on the front, on recession or at change of a signal. For more information see function attachInterrupt ().
- **PWM: outputs 3, 5, 6, 9, 10 and 11.** By means of function analogWrite () can display 8-bit analog values in the form of a PWM signal.
- **SPI interface: outputs 10 (SS), 11 (MOSI), 12 (MISO), 13 (SCK).** These outputs allow to carry out communication via SPI interface. In the device hardware support of SPI is implemented, however at the moment language of Arduino does not support her so far.
- **LED: output 13.** The built-in LED connected to a digital output 13. When sending HIGH value the LED joins, when sending LOW - is switched off.

  In Arduino Ethernet there are 8 analog inputs, each of which can present analog tension in the form of 10-bit number (1024 different values). By default, strain measurement is carried out concerning range from 0 to 5 V. Nevertheless, the upper bound of this range can be changed, using an output of AREF and function analogReference (). In addition, some of outputs have additional functions:
- **I2C: outputs 4 (SDA) and 5 (SCL).** With use of Wire library (documentation on the Wiring website) these outputs can carry out communication via I2C (TWI) interface.

  In addition to listed on a payment there are some more outputs:

- **AREF.** Reference voltage for analog inputs. It can be involved by function analogReference ().

- **Reset.** Forming of the low level (LOW) on this output will lead to reset of the microcontroller. Usually this output serves for functioning of the button of reset on expansion cards

You watch also compliance of outputs of Arduino and ATmega168.[14]

5.1.7 Communication

Arduino Nano gives a number of opportunities for implementation of contact with the computer, one more Arduino or other microcontrollers. In ATmega168 and ATmega328 there is an UART transceiver allowing to carry out communication according to serial interfaces by means of digital outputs 0 (RX) and 1 (TX). The chip of FTDI FT232RL provides communication of the transceiver with USB port of the computer, and at connection to the PC allows Arduino to be defined as virtual COM port (drivers of FTDI are included in a software package of Arduino). The software package of Arduino also includes the special program allowing to read out and send simple text data to Arduino. At data transmission to the computer through USB on a payment LEDs of RX and TX will blink. (At serial data transmission by means of outputs 0 and 1 these LEDs are not involved).

The SoftwareSerial library allows to implement consecutive communication on any digital outputs of Arduino Nano.

In ATmega328 and ATmega168 microcontrollers support of the serial interfaces I2C (TWI) and SPI is also implemented. The software of Arduino includes the Wire library allowing to simplify work with the bus I2C; for obtaining more detailed information see documentation. For work with the SPI interface see datashita of ATmega168 and ATmega328 microcontrollers

.

5.1.8 Programming

ATmega168 and ATmega328 in Arduino Nano is issued with the stitched loader allowing to load into the microcontroller new programs without the need for use of an external programmator. Interaction with it is carried out under original STK500 protocol.

Nevertheless, the microcontroller can be stitched also via the connector for onboard programming of ICSP (In-Circuit Serial Programming), without paying attention to the loader.

5.1.9 Automatic (program) reset

.

That every time before program load was not required to click reset, Arduino Nano is designed thus which allows to carry out its reset programmatically from the connected computer. One of outputs of a chip of FT232RL participating in dataflow control (DTR) is connected to an output of RESET of the ATmega168 or ATmega328 microcontroller via the condenser of 100 нФ. When on the DTR line there is zero, RESET output also passes into the low level for time sufficient for reset of the microcontroller. This feature is used in order that it was possible to stitch the microcontroller only one clicking of the button in coding environment of Arduino. Such architecture allows to reduce a loader timeout as process of a firmware is always synchronized with recession of a signal on the DTR line. Such architecture allows to reduce a loader timeout as process of a firmware is always synchronized with recession of a signal on the DTR line.

However this system can lead also to other effects. At connection of Arduino Nano to the computers working at Mac OS X or Linux, its microcontroller will be reset at each connection of the software with a payment. After reset on Arduino Nano the loader for a while about a half a second becomes more active. In spite of the fact that the loader is programmed to ignore foreign data (i.e. all data which are not concerning process of a firmware of the new program), it can intercept several first bytes of data from the sending sent to a payment right after connection setup. Respectively, if receiving from the computer of any settings or other data at the first start is provided in the program working for Arduino, be convinced that the software with which Arduino interacts carries out sending a second later after connection setup. [15]

5.2 The expansion card Nano Shield for Arduino Nano

Fig. 5.3. Shield

Arduino Nano IO Expansion Shield (Fig. 5.3) is specially developed for simple connection between Arduino Nano and other devices. Actually, it expands the Arduino Nano controller to connect these devices by an easy way. It is ideal addition to the Nano controller and is compatible to Arduino Nano v3.x.

Except standard outputs of the controller there are several contact blocks of additional assignment – power buses 3.3B and the General, the I2C interface (4 groups!) and serial interface UART. All interface connectors are complemented with power supply contacts. On a payment additional power conditioner 5B 900 of a mA and the standard connector of connection of an external power supply is installed. [16][17]

5.3 Servo actuator

5.3.1 Description

The servo actuator is any type of the mechanical drive (devices, an operating part) having the sensor in structure (provisions, speeds, efforts, etc.) and the control box the drive (the electronic circuit or a mechanical system of drafts) which is automatically supporting necessary parameters on the sensor (and, respectively, on the device) according to the set external value (to the provision of a control knob or numerical value from other systems).

In other words, the servo actuator is "an automatic exact performer" — receiving on an input value of managing parameter (in real time), he "by own efforts" (based on indications of the sensor) aims to create and maintain this value on an output of an executive element.

To servo actuators as to category of drives, the set of different regulators and negative feedback amplifiers, for example, gidro-, electro-, pneumatic amplifiers of the manual drive of controlling units belongs (in particular, steering and the brake system on tractors and cars), however the term "servo actuator" most often (and in this article) is used for designation of the electric actuator with feedback coupling by situation applied in automatic systems to the drive of controlling units and operating parts.

Servo actuators are used in the high-performance equipment of the following industries now: mechanical engineering; automatic transfer lines of production: drinks, packaging, building materials, electronics, etc., hoisting-and-transport equipment; polygraphy; woodworking, food industry.

5.3.2 Structure of the servo actuator

The drive — for example, an electric motor with a reducer, or pneumatic cylinder,

The feedback sensor — for example, the sensor of a turning angle of an output shaft of a reducer (enkoder),

The power supply and managements (it is frequency converter / servoamplifier / inverter / servodrive).

The input/converter/sensor of a control signal / influence (can be as a part of control box).

The simplest control box of the electric servo actuator can be constructed on the comparison circuit of values of the feedback sensor and the set value, with giving of tension of the corresponding polarity (via the relay) on the electric motor. More complex circuits (on microprocessors) can consider inertia of the given element and implement smooth acceleration and braking by the electric motor for reduction of dynamic loads and more exact positioning (for example, a head actuator in modern hard drives).

For control of servo actuators or groups of servo actuators it is possible to use the special CNC controllerswhich can be constructed on the basis of the programmable logic controllers (PLC).

Power of engines: from 0.05 to 15 kW.

Torsional moments (rated): from 0.15 to 50 N · m.

5.3.3 Comparison with the stepping motor

Other option of exact positioning of the given elements without feedback sensor is use of the stepping motor. In this case the control circuit counts necessary quantity of impulses (steps) from the provision of a reference point (characteristic noise of the stepping motor in disk drives 3.5" and CD/DVD is obliged to this feature in attempts of repeated reading). At the same time exact positioning is provided with parametric systems with negative feedback which are formed by the corresponding poles of the stator and a rotor of the stepping motor interacting among themselves. The record of a task for the corresponding parametric system is originated by the management system the stepping motor activating the corresponding pole of the stator.

As the sensor usually controls the given element, the electric servo actuator has the following **advantages in front of the stepping motor**:

- does not impose special requirements to the electric motor and a reducer — they can be practically any necessary type and power (and stepping motors are, as a rule, low-power also tikhokhodna);
- guarantees the maximum accuracy, automatically compensating:
    - mechanical (backlashes in the drive) or electronic failures of the drive;
    - the gradual wear of the drive, for this purpose is required to the step engine a periodic adjustment;
    - thermal expansion of the drive (during the work or seasonal), it was one of the reasons of transition to the servo actuator for positioning of heads in hard drives;
    - providing immediate identification of failure (failure) of the drive (by a mechanical part or electronics);

- big possible traverse speed of an element (at the stepping motor the smallest maximum speed in comparison with other types of electric motors);
- expenses of energy are proportional to the element resistance (on the stepping motor rated voltage with a stock on a possible overload constantly moves);

Shortcomings in comparison with the stepping motor

- need for an additional element — the sensor;
- more difficult control box and logic of its work (processing of results of the sensor and the choice of managing influence, and at the heart of the controller of the stepping motor — just the counter is required);
- fixation problem: usually decides constant snubbing of the moved element or shaft of the electric motor (that leads to losses of energy) or use of worm/screw gears (construction complication) (in the stepping motor each step is fixed by the engine).
- servo actuators are, as a rule, more expensive than step.

However, it is possible to use the servo actuator also on the basis of the stepping motor or in addition to it having to some extent combined their advantages and having eliminated the competition between them (the servo actuator carries out rough positioning in an area of coverage of the corresponding parametric system of the stepping motor, and the last carries out final positioning at rather big moment and fixing of situation).

There is no problem of fixation any in the servo actuator unlike step. High-precision positioning and deduction in the set position is provided employment the electrical machine in the valve mode which essence comes down to its work as a power source. Depending on a situation mismatch (and other coordinates of the electric drive) the task for force forms. At the same time undoubted advantage of the servo actuator is the energy efficiency: current moves only in that the volume necessary for this purpose to hold an operating part in a standard position.

Contrary to the step mode when the maximum value of current defining angular characteristic of the machine moves. Angular characteristic of the machine is similar at small deviations to a mechanical spring which tries "attract" an operating part in the necessary point. In a band stepper actuator the more a situation mismatch, the more force at invariable current.

5.3.4 Types of the servo actuator

1. Servo actuator of rotational motion

- Synchronous
- Asynchronous

2. Servo actuator of the linear movement

- Flat
- Round

The synchronous servo actuator — allows to set precisely a turning angle (to within angular minutes), the rotational speed, acceleration. Disperses quicker asynchronous, but is many times more expensive.

The asynchronous servo actuator (The asynchronous machine with the speed sensor) — allows to set precisely speed, even on low turns.

Linear engines — can develop huge accelerations (to 70 m/s^2).

3. By an operation principle

- Electromechanical
- Electrohydromechanical

At **the electromechanical servo actuator** the movement forms the electric motor and a reducer.

At **the electrohydromechanical servo actuator** the movement forms a system the piston cylinder. At these servo actuators high-speed performance is 10 times more in comparison with electromechanical.

5.3.5 Application

Servo actuators are used to exact (on the sensor) positioning (most often) of the given element in automatic systems:

- controlling units of a mechanical system (valves, latches, turning angles)
- operating parts and preparations in machines and tools

Servo actuators **of rotational** motion are used for:

- Industrial robots.
- CNC machines.
- Polygraphic machines.
- Industrial sewing machines.
- Packaging machines.
- Priborov.
- Aviamodelling.

Servo actuators **of the linear** movement are used, for example, in automatic machines of installation of electronic components on the printed circuit board.

5.3.6 Servomotor

The servomotor — the servo actuator with the motor intended for moving of an output shaft to the necessary situation (according to a control signal) and automatic active deduction of this situation.

Servomotors are used to starting of the devices managed by turn of a shaft — as opening and closing of valves, switches and so on.

Important characteristics of the servomotor are dynamics of the engine, uniformity of the movement, energy efficiency.

Servomotors are widely used in the industry, for example, in metallurgy, in CNC machines, the presso-stamping equipment, automotive industry, the traction rolling stock of the railroads.

Generally in servo actuators 3-polar collector engines in which the heavy rotor with windings rotates in magnets were used.

The first improvement which was applied — increase in quantity of windings up to 5. Thus, the turning couple and speed of acceleration grew. The second improvement is a change of construction of the motor. It is very difficult to untwist the steel core with windings quickly. Therefore construction was changed — windings are outside of magnets and rotation of the steel core is excluded. Thus, engine weight decreased, the start time decreased and cost increased.Well and at last, the third step — use of beskollektorny engines. At beskollektorny engines the efficiency as there are no brushes and the sliding contacts is higher. They are more effective, provide the big power, speed, acceleration, a turning couple. [18]

5.3.7 Servo actuator Futaba S3003

Fig. 5.4. Servo actuator Futaba S3003

Detailed Specifications			
Control System:	+Pulse Width Control 1520usec Neutral	Current Drain (4.8V):	7.2mA/idle
Required Pulse:	3-5 Volt Peak to Peak Square Wave	Current Drain (6.0V):	8mA/idle
Operating Voltage:	4.8-6.0 Volts	Direction:	Counter Clockwise/Pulse Traveling 1520-1900usec
Operating Temperature Range:	-20 to +60 Degree C	Motor Type:	3 Pole Ferrite
Operating Speed (4.8V):	0.23sec/60 degrees at no load	Potentiometer Drive:	Indirect Drive
Operating Speed (6.0V):	0.19sec/60 degrees at no load	Bearing Type:	Plastic Bearing
Stall Torque (4.8V):	44 oz/in. (3.2kg.cm)	Gear Type:	All Nylon Gears
Stall Torque (6.0V):	56.8 oz/in. (4.1kg.cm)	Connector Wire Length:	12"
Operating Angle:	45 Deg. one side pulse traveling 400usec	Dimensions:	1.6" x 0.8"x 1.4" (41 x 20 x 36mm)
360 Modifiable:	Yes	Weight:	1.3oz. (37.2g)

5.4 Electromiography sensor

5.4.1 Electromyography: what is it?

Electromyography – the method of diagnostics of violations of a neuromuscular system based on indicators of bioelectric activity of muscles. The ability of muscular tissue to create electric activity at each reduction is the cornerstone of a research. The electromyography registers these values therefore assessment of the received results is made. Depending on indicators, considering the accompanying clinical picture, the defeat center, its localization is defined.

EMG is carried out by means of the electromyograph. The device registers bioelectric activity, transferring it to screens of the monitor or making record on paper. Any deviation from normal values testifies in favor of violation of muscular conductivity.

For removal of an electromyography several methods of a research are used. The choice of a type of EMG is carried out by the attending physician on the basis of specific features of development of a disease. This research of nervous conductivity of muscles is used in the different fields of medicine: neurology, traumatology and orthopedics, cosmetology, stomatology, sports medicine. The electromyography allows to set the pathological center at early stages of a disease. Besides, EMG is used for the purpose of control of the carried-out treatment.

Carrying out an electromyography allows to set:

- Localization of the pathological center.
- Nature of pathology. Defeat of muscle or nervous fibers is defined.
- Extent of distribution of process.
- Disease stage.
- Damage level. Presence of a local or system disease is possible. Depending on it the type of a research is selected.
- Dynamics of pathological process. The doctor exercises control of the assigned treatment by means of carrying out an electromyography in dynamics. It allows to correct or continue earlier assigned therapy in time.

5.4.2 Types Electromiography

There are several ways of carrying out an electromyography. The choice of a method is carried out by the doctor depending on available pathologies. Select the following types of EMG:

- Stimulation (superficial) electromyography. Is to noninvasive and a painless research. This EMG method allows to estimate bioelectric activity on big section of muscles. The stimulation myography is carried out on the lower and upper extremities with a research objective of weakness, fatigue, numbness, decrease in sensitivity of muscles. Besides, superficial EMG is carried out for diagnostics of damage of nerves. This type of a research estimates a condition of chewing and mimic muscles that is informative for cosmetologists and stomatologists.

- Needle (local) electromyography. It is used for more exact research. For this purpose the needle electrode is entered into a muscle. At the same time there is an insignificant morbidity which shortly passes. The local electromyography belongs to an invasive method of a research. In this regard after the procedure developing of hematomas or infiltrates is possible.

Any of the EMG methods is carried out for diagnostics and assessment of treatment. [19]

5.4.3 MyoWare Muscle Sensor

Fig. 5.5. MyoWare Muscle Sensor

Three-lead Differential Muscle/Electromyography Sensor for Microcontroller Applications.

This muscle sensor (Fig. 5.5) from Advancer Technologies measures a muscle's activity by monitoring the electric potential generated by muscle cells. This is referred to as electromyography (EMG). The sensor amplifies and processes the complex electrical activity of a muscle and converts it into a simple analog signal that can easily be read by any microcontroller with an analog-to-digital converter (ADC), such as an A-Star or Arduino – or even a Maestro servo controller as shown in the video above. As the target muscle group flexes, sensor's output voltage increases. The exact relationship between the output voltage and the muscle activity can be fine-tuned using an on-board gain potentiometer.

A cable is included for connecting three electrodes to the muscle sensor board. One end of the cable is terminated with a single 3.5 mm audio-style connector that can be plugged directly into the board. The opposite end has three snap-style connectors to make it easy to attach and detach electrodes. Please note that the six included sample electrodes are intended to be single use; replacement electrodes are available directly from Advancer Technologies or from medical supply stores. The board's power and signal pins have a 0.1 ″ pitch and work with 0.1 ″ male headers and 0.1 ″ female headers.

For more detailed information about the muscle sensor, including instructions on how to use it, see the Advancer Technologies Muscle Sensor v3 user's manual (409k pdf). Example Arduino programs can be found on their GitHub page.

Warning: This sensor's output signal can be as high as the supply voltage (Vs). If you are using a supply voltage higher than the rest of your system can handle, we recommend using the gain potentiometer to adjust the sensor's maximum output to an appropriate voltage before connecting the signal line to the rest of your system. Alternatively, you could lower the output voltage using an external circuit such as a voltage divider before connecting it to your microcontroller. [20]

FEATURES

- Small Form Factor (1inch X 1inch)
- Specially Designed For Microcontrollers

- Adjustable Gain – Improved Ruggedness

- New On-board 3.5mm Cable Port

- Pins Fit Easily on Standard Breadboards Muscle Sensor v3

APPLICATIONS

- Video games

- Robots

- Medical Devices

- Wearable/Mobile Electronics

- Powered Exoskeleton suits

5.4.4 Sensor connection

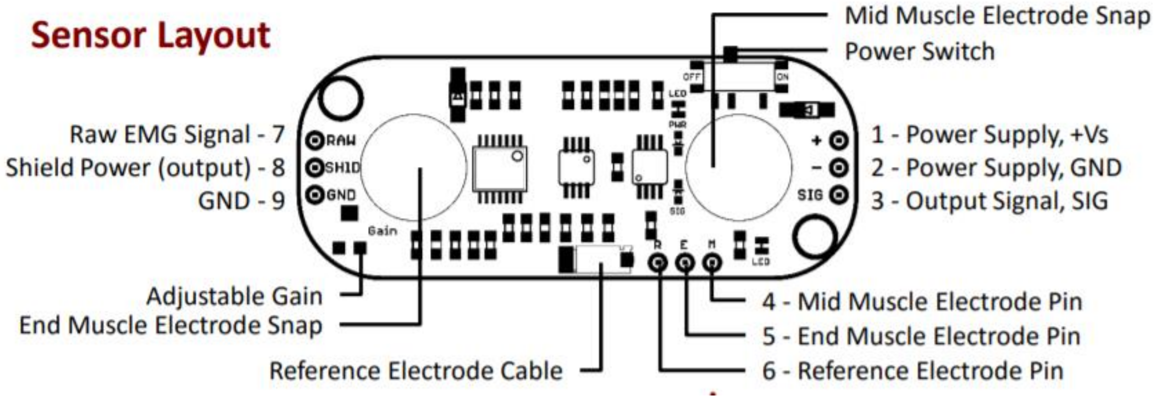


Fig. 5.6 MyoWare Muscle Sensor

Getting Started Using 3V

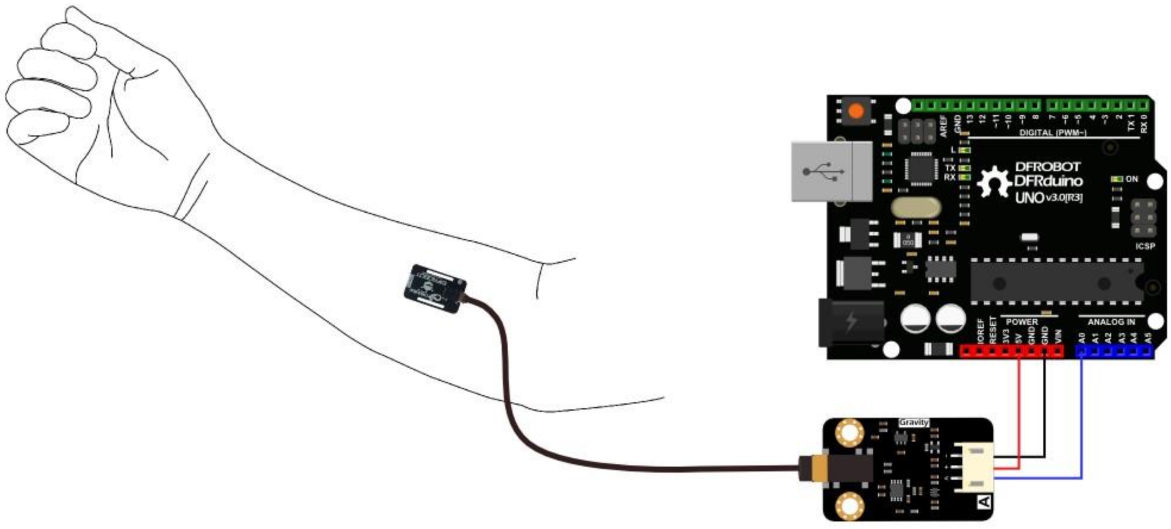


Fig. 5.7. Muscle Sensor wiring diagram

1) Connect the power supply.

2) Connect the electrodes a. After determining which muscle group you want to target (e.g. bicep, forearm, calf), clean the skin thoroughly. b. Place one electrode in the middle of the muscle body, connect this electrode to the RED Cable’s snap connector. c. Place a second electrode at one end of the muscle body, connect this electrode to the Blue Cable’s snap connector. d. Place a third electrode on a bony or non-muscular part of your body near the targeted muscle, connect this electrode to the Black Cable’s snap connector.

3) Connect to a Microcontroller (e.g. Arduino) (Fig. 4.7) of a. Connect the SIG pin of your sensor to an analog pin on the Arduino (e.g. A0) b. Connect the GND pin of your sensor to a GND pin on the Arduino.

5.4.5 Circuit Schematic

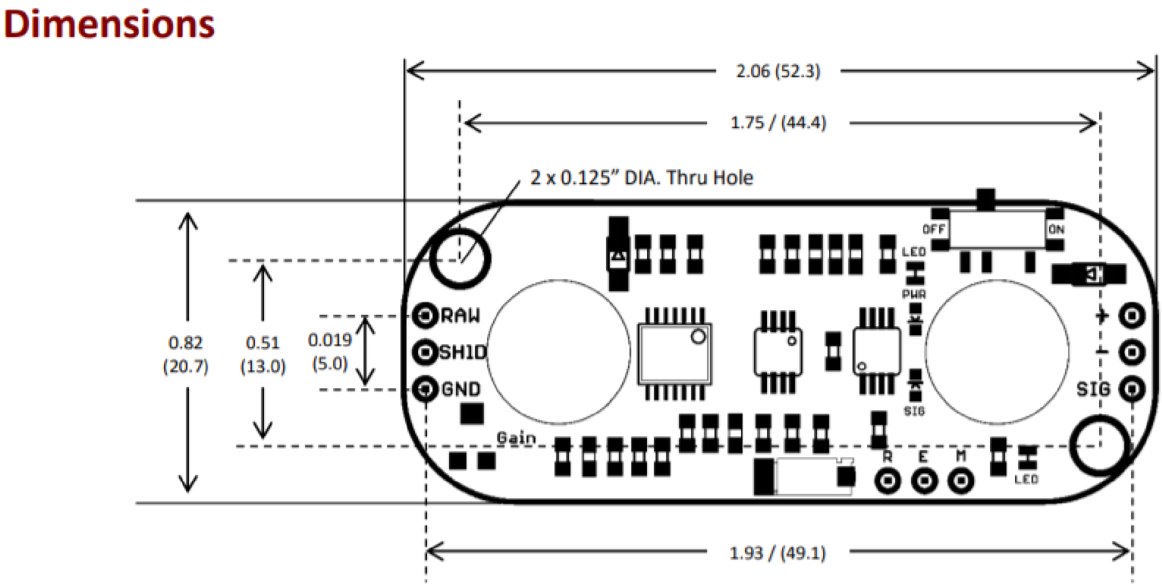
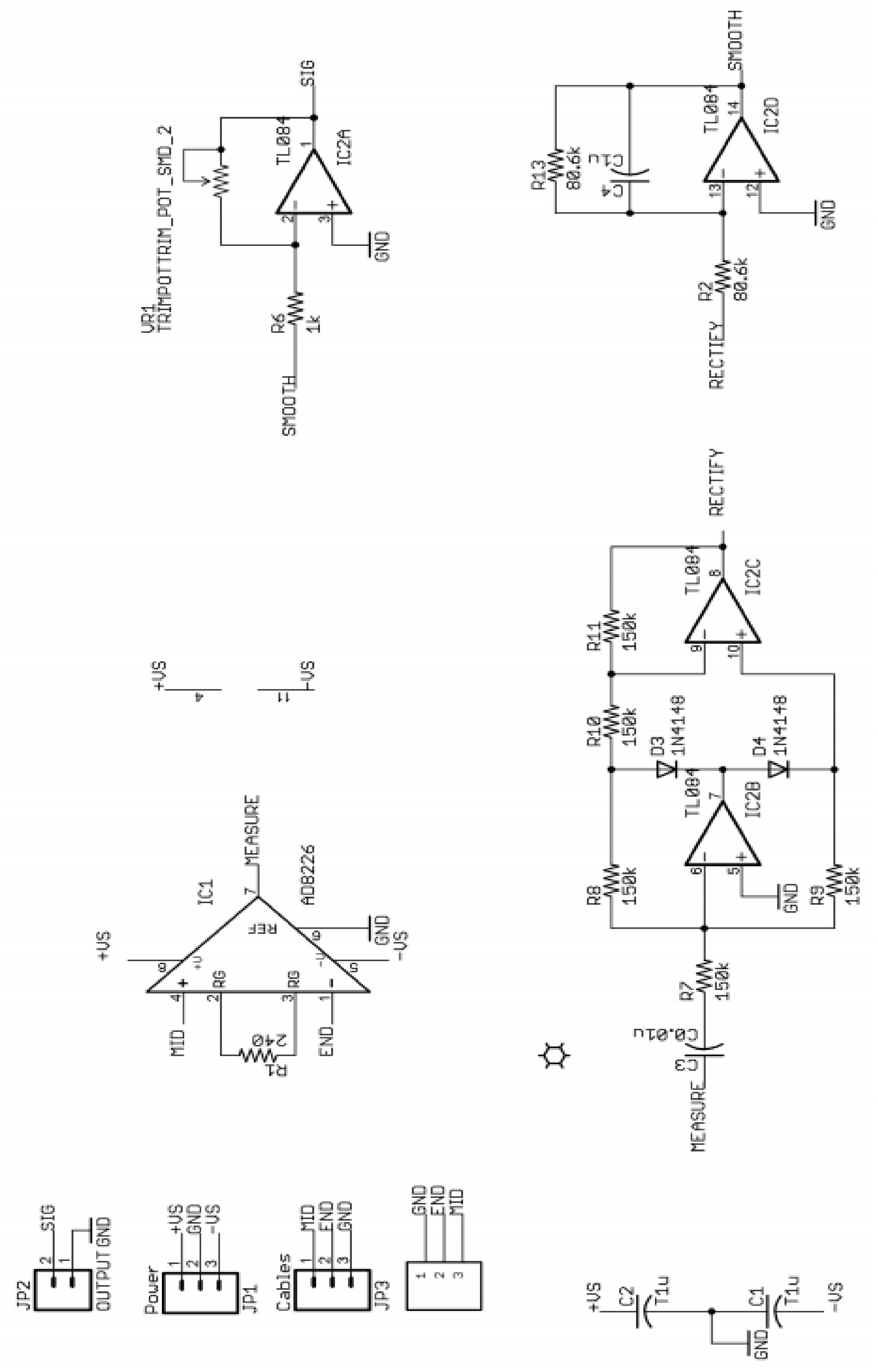


Fig. 5.8. MyoWare Muscle Sensor Dimensions

For a complete understanding of the size of the sensor in Figure 5.8, all sizes are shown

A detailed schematic description of this sensor is shown in Figure 5.9.

Fig. 5.9 MyoWare Muscle Sensor circuit



4.4.6 Electrical Specifications

Parameter	Min	TYP	Max
Supply Voltage	+2.9V	+3.3V or +5V	+5.7V
Adjustable Gain Potentiometer	0.01 Ω	50 kΩ	100 kΩ
Output Signal Voltage EMG Envelope Raw EMG (centered about +Vs/2)	 0V 0V	 -- --	 +Vs +Vs
Input Impedance	--	110 GΩ	--
Supply Current	--	9 mA	14 mA
Common Mode Rejection Ratio (CMRR)	--	110	--
Input Bias	--	1 pA	--

ELECTROSTATIC DISCHARGE SENSITIVITY

This sensor can be damaged by ESD. Advancer Technologies recommends that all sensors be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage. ESD damage can range from subtle performance degradation to complete device failure.

5.4.7 Rectified & Smoothed Electromiography

Our Muscle Sensors are designed to be used directly with a microcontroller. Therefore, our sensors do not output a RAW EMG signal but rather an amplified, rectified, and smoothed signal (Fig. 4.10) that will work well with a microcontroller’s analog-to-digital converter (ADC). This difference can be illustrated by using a simple sine wave as an example.[21]

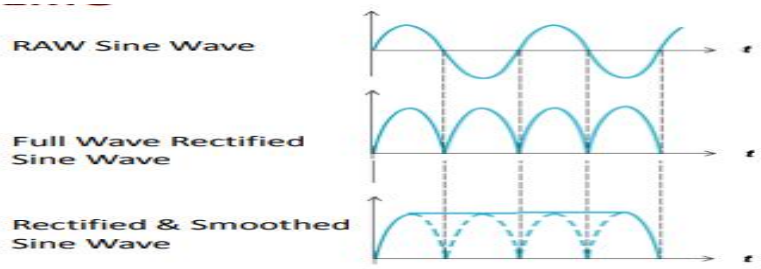


Fig. 5.10 signal change

Chapter 6

The mechanical part of the bioprosthesis

My prosthesis consists of 36 elements (Fig. 6.1) printed on a 3D printer.

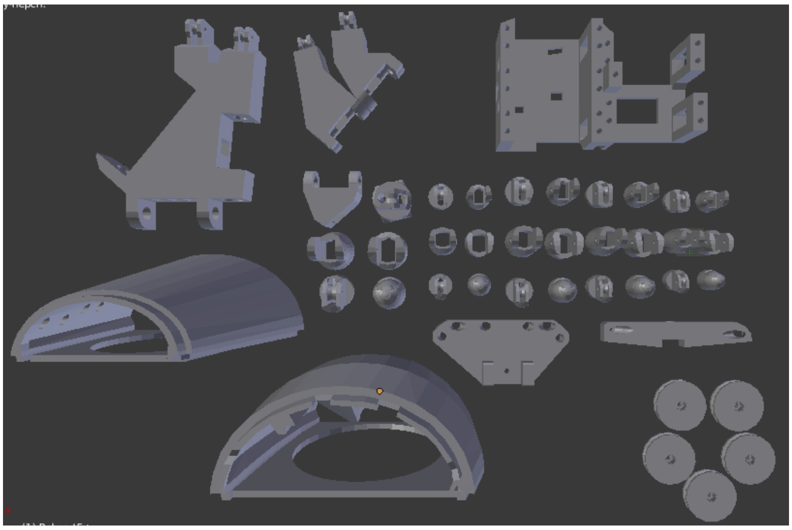


Fig. 6.1. Elements for 3D printing

Since the hand is quite a large and complex object, it is divided into several main parts. Some parts are connected with glue, moving parts with hinges.

Since the main task of the bionic prosthesis is a flexion function, a servomotor that leads to a fishing line stretched across the entire brush and a finger attached to the fingertip leads it to a bent position. Thus, the finger is bent.

Rubber is used for extension, fixed at one end at the tip of the finger and at the hinge at the other end in the area of the hand. The main part of the rubber is in the finger for the line. Thus, when the line is relaxed, the rubber pulls the finger to the starting position.

There are a number of drawbacks to this mechanism. But they can be modified while improving the prosthesis mechanism itself.

Chapter 7

Control scheme

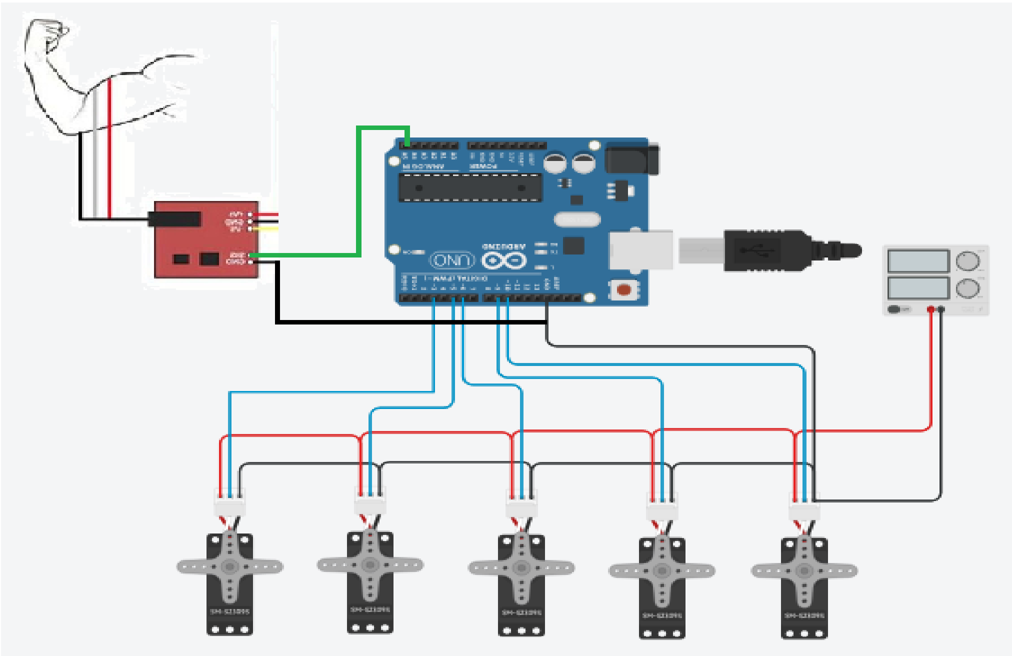


Fig. 7.1. Connection diagram of all components.

Logical part

The controller (ARDUINO) is responsible for the logic in the system(Fig. 7.1). It is entrusted with the task of calculations. The main task of the controller is to take the values coming from the muscle sensor (problems regarding this aspect will be considered further), the control of the position of the servos and the calibration of the system.

Sensors

In these devices, it is quite logical to use a variety of sensors (temperature, pressure, ...) and user feedback. In view of the development of new growth, I decided to use these technologies in subsequent samples.

For reading muscular activity, the “Muscle Sensor v3” sensor is used. The complexity of connecting this sensor is its power. Do not forget about the correct choice of the appropriate muscle group for the correct operation of the sensor.

Power unit

The power part of this device are servomotors. It is they who make the fingers bend and hold a certain weight.

Power supply

For the controller itself, 5V voltage is sufficient.

More capricious to nutrition is the muscle sensor. It requires 3V.

Since the five servos are quite energy consuming, they require a separate 12V 2A power supply.

In the future we plan to use one power source in the form of four batteries of 4V each which will be connected in series(Fig. 7.2).

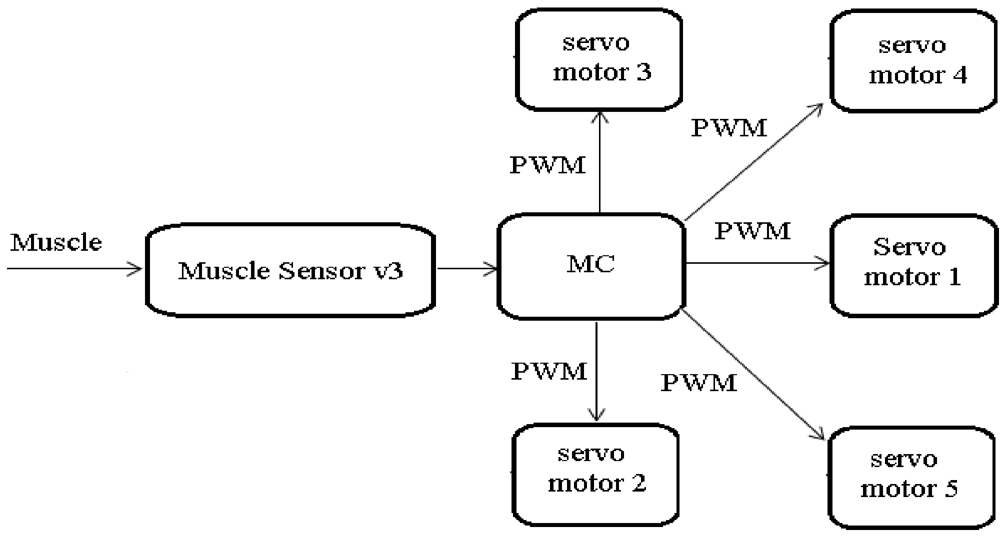


Fig. 7.2. Block control circuit

CHAPTER 10

OCCUPATINAL SAFETY

Workplace safety is one of the key concerns of every manufacturing company and facility. Getting it right can help the whole operation's performance and results grow, while safety issues may cost you time, money, injuries, and even reputational damages. So you want to take really good care of that before anything bad happens. And unfortunately, bad things do happen.

In 50 years, since President Richard Nixon signed into law the Occupational Safety and Health (OSH) Act, the incidence rate of nonfatal injuries at workplaces has dropped from the average of 10.9 cases per 100 full-time workers in 1972 to the average of 2.8 cases in 2018, but there's still a long way to go.

Still today, over 100,000 manufacturing workers are becoming victims of job-related injuries every year. Even with OSHA's regulations and rules, manufacturing companies must have a company culture that embodies a safety attitude.

Thanks to our extensive experience working with manufacturing companies, we were able to collect and explore the best safety practices in manufacturing, and the following article is a summary of what we've learned.

To put it simply, our own and our clients' experience proves that investing the time and money in thorough workplace safety training will save you a ton on churn, sick leave, and medical insurance payments, in the long run, utilizing safety checklists and workflows will help workers stay alert and ready, reducing the risk of incidents, and using dedicated modern software solutions for manufacturing management for immediate reporting and constant control over the facility will raise the overall safety standards and help increase the flawless production performance rates.

Connecteam is proud to be the employee management app of choice for many manufacturing companies, and their most common use cases include:

1. Raising Safety Standards and Awareness
2. Day-to-Day Digital Reporting and Checklists
3. Streamlining Communication to Deskless Employees
4. Making SOPs and Company Protocols Available
5. Human Resources needs
6. Compliance Purposes
7. Training

Learn from others' mistakes and save yourself some serious cash and time by following these 13 safety ideas for manufacturing. What you need are the best strategies to build a world-class safety program and culture to positively impact your bottom line.

It is so stupid. In my diploma thesis I present a prototype and I do not plan hire hundreds of people for this project and takes care of their safety. I do not plan to start mass production and create a factory in order at this stage to discuss topics like "Analysis of harmful and dangerous production factors" and "Measures to reduce the impact of harmful and dangerous production factors". It's a waste of my and your time!

Such a production will not be built overnight. Let's think modern!

10.1Prevent Risks by Early Reporting

If you're an employee — don't be afraid to take initiative. When it comes to your own and your colleagues' safety — there is no playing too safe!

Whenever you're at the workplace and spot something that has the potential to go wrong — fix it if you can, or raise the flag!

As soon as there's something that is potentially unsafe, or at least you think might be — don't take chances and report it to your supervisor or the responsible manager.

If you are a manager, and especially a safety manager — it is your moral and legal obligation to keep your people and their working environment safe and take immediate actions to guarantee it. Let them help you by embedding the early warning strategy.

A dripping hose, an open window, a loose bolt, or even a wet floor might cause incidents, damages, or even injuries — so make sure every hazard possibility is taken seriously and reported right away.

Stimulate people to be alert and report anything they are unsure about, in order to locate possible hazards before they bring damages.

10.2 Create And Follow Checklists To Never Miss Important Stuff Again

You must identify everything that can lead to a hazard before you plan the safety protocols at your company. Use the following checklist to determine potential hazards:

- What service/product is the company providing?
- What machinery will employees be exposed to and need to operate?
- Are there any hazardous chemicals present in the workplace?
- Is there a likelihood of fall risks in the workplace?

Create a checklist that also includes hazards like fire, electrical, and ergonomic, you can find sample programs from the Occupational Safety and Health Administration (OSHA) website to know exactly what topics to cover. You must identify anything that your employees can be exposed to in order to create a process on how the material should be safely used and what to do in case of an incident. Most categories have OSHA-certified guidelines that are typically consistent across industries so customize your protocols to these procedures.

Now that you have identified the risks, you must also prepare checklists for your employees. The most common checklists include, but are not limited to:

- Safety hazard observation
- Incident report
- Vehicle accident report
- Safety inspection form (for supervisors)
- Repair order ticket
- QA checklist
- Safety inspection checklist.

When employees must go through a checklist when arriving at the job site or before using equipment, the chances of incidents or injuries drop dramatically. Plus, daily operations are a key component for many manufacturing companies, therefore checklists are frequently used in order to reduce friction from day-to-day activities, automate the flow of information, improve response time, and gain better oversight.

10.3 Embed Safety Culture Into Your Company's DNA

You can't create a safe workplace and environment just through safe equipment and procedures alone. True safety in the manufacturing industry can be achieved only by building a safety-focused company culture where every single employee feels responsible and empowered to alert managers to safety concerns.

“Schneider Electric’s motto is work safe, watch out for each other. If you’re not 100% sure you can complete a job safely, stop work. It’s not enough to keep yourself safe. You need to think and act to prevent hazards for the next person.” – Jim Spurlock, staff safety and environmental engineer.

When employees lead the safety processes, from management to the field, everyone is involved in every part of the company’s safety efforts so hazard reporting and corrective actions are on all staff members to execute. This kind of safety culture helps build ownership across the entire company.

Here’s one great example of a manufacturing company which considers safety culture a top priority:

Make sure that you let your employees know that they’re protected by OSHA and will not be reprimanded for calling attention to problems. Encourage everyone to speak up because a strong safety culture can help promote low injury rates and lowers turnover rates. Make sure every employee is familiar with the top workplace safety tips.

10.4 Make Wearing Safety Gear A No-Brainer

Operating with and close to heavy objects and machinery, exposure to toxic materials, working in dark and cluttered spaces — all of the above can affect people’s health as well as expose the factory to potential risks like fires, explosions, accidents, and injuries. That’s why using safety gear and wearing protective clothing should be an absolute must for all employees at all times.

Whenever cleaning messes and using equipment at the workplace, you have to be wearing the proper safety equipment. If your company uses checklists, then you can go through the list to ensure nothing has been missed. When you are wearing the proper safety equipment and are thoroughly checking that your safety equipment is not damaged, the risk of injury is significantly lower.

10.5 Make Sure The Equipment, Tools, And Machines Are Used Properly

The most prevalent source of workplace injuries is the misuse of tools and machines. When you are handling equipment, you have to ensure that you use each equipment piece as intended and the correct way.

OSHA cites the following as five basic rules to help prevent hazards or incidents when handling equipment, tools, and machines:

- Maintain tools in good working condition with regular maintenance.
- The right tool must be used for the job.
- Careful examination of each tool for damage before use and using damaged tools are not appropriate.
- Use and operate tools according to the manufacturing instructions.
- Properly use the correct protective equipment.

Additionally, watch this Oregon OSHA's video on Hazards identification:

10.6 Communicate Often With Your Employees

When you have two-way communication, you provide your employees with the opportunity to shape workplace safety. Through daily and monthly safety meetings, you are able to influence and prepare everyone on safety matters – discuss what went wrong, what was acted on and what needs to be fixed, and all ongoing safety projects. Ask your employees for input and be sure to give a congratulatory shoutout to departments that were injury-free.

“Safety is the very first thing we talk about at daily meetings. Any injury, first aid incident, or unsafe condition is always brought up first.” – Rex Krohn Jr., manager of global paint at John Deere

This kind of two-way street helps to reduce misunderstandings, keeps everyone on the same page, nothing slips between the cracks, productivity is boosted, the gap between managers and employees narrows, and everyone has a chance to be heard.

We created a free eBook that offers actionable tips and easy-to-implement strategies for managers that are looking to build and maintain an effective internal communication strategy.

10.7 Promote The Culture Of Frequent Breaks

A lot of injuries occur when employees are too tired and are not able to observe the dangers surrounding them adequately. Additionally, repetitive actions and activities can lead to fatigue, especially when handling machines. By ensuring everyone takes regular breaks, you can stay more alert when on the clock.

Consider offering your personnel some fun activities in the middle of a long shift, like an all-hands 10-minute warm-up, stretching-session, or even team-building games, to have some rest from the routine work, relieve some stress and boost the morale.

10.8 Keep The Workspace Clean And Organized

By keeping the workplace clean, you can help prevent many injuries from happening. It is important to follow the six “s” rule – sort, straighten, shine, standardize, sustain, and safety.

10.9 Prevent Slips And Falls

As the second most prevalent cause of nonfatal occupational injuries, it is crucial that aisles are clear and spills are properly cleaned to prevent employees from injury. Another workplace safety tip is when dealing with liquids, use drip pans and guards, clean spills immediately in order to keep conditions safe, and be sure to check your workplace to ensure there are no holes, loose boards, or nails projecting from the floor. If any of these hazards are noted, be sure to replace or fix the item.

10.10 Promote Safe Work Techniques and Workplace Ergonomics

Having a good posture in the manufacturing industry actually leads to better productivity. Poor or bad posture adds unnecessary strain to the joints, muscles, and ligaments which can lead to more serious injury later on.

When lifting, follow these simple tips:

- Get help when lifting heavy or awkward objects.
- Have a firm grasp on the object before lifting.
- Have firm and good fitting when lifting heavy objects.
- Maintain a wide stance and get close to the object before you need to lift.
- Never bend at the waist in order to lift objects low to the ground.
- When needing to lift low objects, bend with your knees and hips – your legs should do most of the work.

When driving, be mindful of these tips:

- Do not extend your arms to reach the wheel.
- Your knees need to be able to bend and comfortably reach the pedals.
- Adjust the height of your seat so that your knees are at the same level as your hips or higher.

- Ensure that your back is straight and resting on the back of the seat when driving.
- Use a lumbar roll to add support to the curve of your back.

With mindfulness and practice, maintaining a good posture will come naturally and easily.

10.11 Make Regular Inspections And Check-ups

Create audit checklists for the entire company that each supervisor must go through to review the hazards and safety suggestions within their respective department. Additionally, you can review your system to outline all injuries, illnesses, and near misses so that you can create corrective action for each safety concern, and assign a supervisor to complete the action. When you can rid the root cause of hazards then you create a safe environment for all.

10.12 Network And Share Experience

Work with suppliers, fire and police professionals, and insurance agents to address problem prevention and safety ideas for manufacturing. Together, you can draw up potential hazards and protection for your entire staff. When you have more eyes, especially from the outside, you are able to create a full risk assessment.

"Insurance companies are a valuable resource. Insurance experts can tour your facility, identify hazards, and make recommendations. It isn't a recommendation when OSHA comes. Also, fire professionals can assess potential fire threats and run extinguisher training. And local police can help prepare for and prevent emergencies." – Jon Burk, safety manager at Therma-Tron-X, Inc. (TTX)

10.13 Deliver Consistent Safety Training To Employees

Training is your opportunity to help build risk management into every aspect of your company. This kind of focus provides your employees with the tools they need to protect themselves, your customers, and also your company.

Some training tips for safety ideas for manufacturing include:

- Identify safety concerns for your company.
- Set training goals.
- Develop practical learning activities.

There are numerous regulatory demands that you have to adhere to, from entities like OSHA and state health and safety authorities. Therefore, when you plan your safety training program, make sure your goal isn’t just to comply with regulatory demands, but also to minimize incidents, maximize awareness, and keep employees healthy, happy and productive.

Automate Your Workplace Safety Efforts With an All-In-One Company App

Hundreds of manufacturing companies choose Connecteam to raise safety standards and awareness, streamline daily processes, boost communication, better compliance, optimize training, and more.

How do manufacturing companies raise safety standards with Connecteam’s all-in-one mobile app?

- Quick and easy reporting makes it easier for all employees to report in real-time, whether in the office or in the field. and automatically send this to the relevant officer/supervisor for further evaluation and response. The following daily reports can be done via mobile, which saves a ton of time, safety hazard observation, incident report, vehicle accident report, safety inspection checklist, expense reimbursement, visitor request form, and so much more.

- Sharing digital resources allows all safety protocols, tips, and resources to be available in a click, along with ‘lessons learned’, incident findings, and periodical safety tips. Resources like standard Operating Procedures (SOPs), employee handbook, code of ethics, emergency procedures, and more are available at a tap.
- Ongoing safety training allows managers and safety officers to keep a close eye on how each employee is doing. In-app training includes health and safety training, driving-related training, equipment usage and maintenance, tests and quizzes, and more.

Streamlining communication and distribution of updates and protocols can be done in the click of a button. Such as sharing incident finding reports, procedure updates, real-time updates on prohibitions, or risk factors like bad weather. Through the in-app directory, it’s easy to find the work contact you need. Start chat groups to better day-to-day communication more easily and efficiently. Or send formal and informal announcements with push notifications.

All of the above may sound ridiculously expensive, but Connecteam, pricing starts at $29/month for up to 200 users! So start your free plan now to benefit from all of Connecteam’s features.

CHAPTER 6.
ENVIRONMENTAL PROTECTION

I don't think my prototype is better than the existing bionic prosthesis. Since at the moment there are not so many companies that produce bionic hand prostheses, no one exposes their developments for open viewing. This makes it very difficult to compare control systems.

My prototype can only compete in the price area since it is much cheaper than products from Europe.

Gore’s respect for the environment is a natural outgrowth of our legacy of responsible innovation. Throughout our history, we’ve applied the principles of sound science to create products that improve the quality of life, including products that help solve difficult environmental challenges. We strive to be good stewards of air, water and energy resources and in our management of waste. It’s our responsibility as a company and as individuals.

For efforts that span our filtration, sealants and other business lines, Gore was awarded the UK Pollution Abatement Technology Award in recognition of our achievements in technology to reduce or prevent pollution. Shortly after, in 1991, we were accepted as a member of the Industrial Gas Cleaning Institute (IGCI), a group of major manufacturers of air pollution equipment. That organization is now called the Institute of Clean Air Companies (ICAC), and we remain a full member.

Our environmental efforts extend to the textiles industry. Gore was a founding member of the Sustainable Apparel Coalition (SAC), an organization whose vision is to help create an apparel and footwear industry “that produces no unnecessary environmental harm and has a positive impact on the people and communities associated with its activities.” Additionally, in 1992, we became one of the first fabrics producers to proactively reduce our environmental footprint by applying a Life Cycle Assessment to our products and processes. To this day, GORE® Fabrics releases an annual Responsibility Update outlining our efforts to remain stewards of the environment.

Industrial manufacturing and processing environments involve harmful chemicals that must absolutely be controlled, both for the workers on-site and the environment around them — especially given the emissions regulations that manufacturers must follow. To keep chemicals under control, vessels, pumps, valves and piping systems require no-fail seals — and they require reliable sealing solutions like those provided by Gore.

Contamination control is a must in so many industries: pharmaceutical, telecommunications, oil and gas, and far more. GORE® Filtration Products help manufacturers meet regulatory requirements and control their processes by capturing 99.9% of particulate emissions from industrial air streams.

In 1973, we launched our first filtration product, a filter bag, which introduced our pioneering concept of "surface filtration." Rather than trapping particles within filter media, which can build up particles and block materials from passing through, our filter media stops and sloughs off particles on the surface of our proprietary ePTFE membrane. In 1979, Asbestos magazine recognized GORE-TEX Filter Bags as the gold standard for filter media in the industry. A few years later, in 1985, we developed the very first working filter bags used in alkali bypass systems in cement plants.

In 1982, we developed our first products for liquid filtration, doing for ground water and other liquid sources what our dry filtration products do for the air. These developments have allowed Gore technology to reduce emissions in mills producing dyes and pigments, plants that produce hazardous liquids, and pharmaceutical processing centers.

Today, we offer numerous filtration products that help protect the environment by capturing harmful particles and contributing to clean air. GORE® Low Emission Filter Bags deliver strict environmental compliance and enhanced product capture. DuPont Plunkett Award-winning GORE® Turbine Filters remove damaging particles from the air intake of a gas turbine engine — thereby reducing the engine's fuel consumption by allowing it to run more efficiently and reliably. The GORE® REMEDIA® Catalytic Filtration System is used in high-temperature industrial operations to destroy harmful furans and dioxins. And our GORE® Mercury Control Systems, available for use in coal-fired broiler or cement applications, are designed specifically to help manufacturers meet regulatory requirements by capturing oxidized and elemental gas phase mercury.

Though they serve many industries, our filtration media serve a common purpose: to create controlled environments, allowing processes to remain environmentally responsible.

Electric cars are growing increasingly popular as a substitute for gas- and diesel-powered cars. Since the 1990s, Gore has contributed to this environmentally responsible manner of powering cars.

We support fuel cell vehicles (FCV) with membrane electrode assemblies (MEAs) and membranes. Our MEA solutions facilitate the electrochemical conversion of hydrogen and oxygen into energy within the fuel stack, powering the vehicle without the use of fuel.

Today, nearly all of the major fuel cell system developers worldwide rely on Gore's MEAs for their stationary, portable and transportation applications. We recently played a vital role in the world's first mass-produced hydrogen fuel cell vehicle; each fuel cell within this vehicle's fuel stack contains a GORE-SELECT® membrane.

As environmental concerns mount, more and more industries are looking for ways to incorporate eco-friendly practices and products. In addition to our sealant, filtration and fuel cell technologies, we offer:

- GORE® Cover System, a microbiological soil remediation product for composting organic waste. The cover helps communities manage waste more efficiently and economically by accelerating the composting process, and also minimizes odors and prevents the transmission of bacteria into the air.
- GORE® Protective Vents for Solar Energy Systems. We are supporters of renewable energy sources, and our vents preserve sensitive electronic components (like concentrator photovoltaics [CPVs], junction boxes and inverters) by preventing exposure to damaging environmental elements and constantly equalizing pressure.
- GORE® Packaging Vents, which prevent containers of industrial, household and agricultural chemicals from leaking or exploding, which can cause great harm to end users and the environment.

Since Gore's founding in 1958, we've felt compelled to share our technological expertise with industries around the globe. So, too, have we felt the need to do so with respect and responsibility for our environment. As manufacturers and industries rethink and change their practices for the better of our planet, we at Gore extend our partnership as innovators who also consider ourselves environmental protectors.

This article presents a comparative analysis of alternative models of production with environmental concerns that may lead to higher effectiveness in initiatives undertaken by industrial firms towards the development of more sustainable operations. The objective is to organize the knowledge on the subject of such models and provide guidelines that may help managers in selecting the most fitting approach for their business, according to the strategy and conditions of the firm. Among the presented models, the Cleaner Production model stands out for promoting the approach of nurturing the concurrent strengthening of quality, productivity, and sustainability in the existing manufacturing processes by dealing more comprehensively with factors internal to the firm that may be directly controlled by the managers.

- The United Nations Environmental Program (UNEP) was created on December 15th, 1972 by a resolution of the United Nations General Assembly (n. 2997 - XXVII), but only 20 years later, in 1992, this program was actually adopted in the United Nations Conference on Environment and Development, called as Agenda 21 (Sitarz, 1993), during the Earth Summit held in Rio de Janeiro (Brazil). Despite these actions, during the Millennium Summit held in year 2.000 in Malmö (Sweden), the UN Secretary-General's reported concerns that the challenges of sustainable development simply overwhelmed the effectiveness of our responses and that with some honorable exceptions, our responses were too few, too little and too slow. Now, after about 40 years since that UN's General Assembly resolution was established, many concerns on sustainable development remain almost in the same position; as key drivers like the actions towards environmental protection that should be deployed by government, technology developers and individual firms are not advancing as expected.
- In manufacturing industry, a major consumer of natural resources and source of pollution, reliable guidelines and parameters for environment control have already been defined. The ISO 14000 standards for environmental management systems introduced in 1996 constitute a relevant instrument to promote them. A growing number of firms worldwide have exploited the certification by these standards as a means to promote and reinforce their approach to environmental management,

however, in a slower pace if compared to the search of ISO 9000 certifications for the quality management system

- The United Nations Industrial Development Organization (UNIDO) believes that competitive and environmentally sustainable industries have a crucial role to play in accelerating economic growth, reducing poverty and thus achieve the so called Millennium Development Goals (United Nations, 2005), which primarily were targeted to be accomplished until 2015. The economic development brings benefits, but on the other hand, it has also been largely responsible for the degradation of the environment and has caused damages that deteriorate the quality of life. Investors, managers, engineers and researchers concerned with manufacturing firms and production systems have crucial roles in the promotion of industrial development with environment protection, to ensure the sustainability of the planet for future generations. Production models with environmental concerns
- Since the establishment of a fundamental policy for sustainable industrial development by UN, a number of approaches were developed and proposed by different organizations to serve as a means to minimize the environmental impact caused by the production system of industrial firms. Based on a literature review of works that consider the propositions of such initiatives and their implementation, the five approaches listed below were identified as those that have been most influential:
- - Adoption of End-of-Pipe technologies for pollution control;
- - Cleaner Production;
- - Green Production or Green Manufacturing;
- - Sustainable Production;
- - Sustainable Production and Consumption.

- The following sections present each of them pointing out their main features.

The adoption of End-of-Pipe technologies is a classical contrivance for pollution control based on devices normally implemented in latter stages of a manufacturing process. They are not part of the production process, but accessories used to mitigate the deleterious effects of emissions generated by the production process. The environmental concern of this model is focused in the control of pollution generation and implies a kind of investment made in industrial plants that does not bring a definitive improvement of the production process in terms of lower emission generation. Furthermore, even if investments are made in the installation of End-of-Pipe technologies, the lack of a sound management system for environmental control may not result in a better environmental performance (Berkel, Willems and Laf-leur, 1997; Rothenberg, Pil and Maxwell, 2001). For example, Hillary and Thorsen (1999) found actions to mitigate water pollution that still had environmental problems due to the deposition of sludge in a landfill, only changing the place of the problem and not solving it definitely.

End-of-Pipe Technologies are the most common approach adopted by the firms because they are of faster and easier implementation, not demanding radical changes in the established management structure. However, End-of-Pipe actions involve much specific technology and still demand considerable investments. This is one of the reasons that could explain why the pace of implementation of environmental protection initiatives have been so slow, as only a small portion of the firms can afford to bear that cost (Moors, Mulder and Vergragt, 2005; Frondel, Horbach and Rennings, 2007). According to Pailthorp (1977), to bring about more effective benefits for the firm, these type of investments should be better planned to allow recycle or re-use of wastes.

The concepts of CP, as conceived by UNEP, constitute a model of production that causes less environmental impacts that should be pursued by industrial organizations through the deployment a set of new practices based on the principles listed in Table 1, which are highlighted by authors like Fresner (1998) and Berkel; Willems and Lafleur (1997).

1. GOOD HOUSEKEEPING: appropriate provisions to prevent leaks and spills and to achieve proper, standardized operation and maintenance procedures and practices;

2. INPUT MATERIAL CHANGE: replacement of hazardous or non-renewable inputs by less hazardous or renewable materials or by materials with a longer service lifetime;

3. BETTER PROCESS CONTROL: modification of the working procedures, machine instructions and process record keeping for operating the processes at higher efficiency and lower rates of waste and emission generation;

4. EQUIPMENT MODIFICATION: modification of the production equipment so as to run the processes at higher efficiency and lower rates of waste and emission generation;

5. TECHNOLOGY CHANGE: replacement of the technology, processing sequence and/or synthesis pathway in order to minimize the rates of waste and emission generation during production;

6. ON-SITE RECOVERY/REUSE: reuse of the wasted materials in the same process or for another useful application within the company;

7. PRODUCTION OF USEFUL BY-PRODUCTS: transformation of previously discarded wastes into materials that can be reused or recycled for another application outside the company; and

8. PRODUCT MODIFICATION: modification of product characteristics in order to minimize the environmental impacts of the product during or after its use (disposal) or to minimize the environmental impacts of its production.

Since 1994, UNEP and UNIDO have worked cooperatively in an international program to foster the implementation of National Cleaner Production Centres (NCPC) as a mechanism to deliver value-added services of Cleaner Production for enterprises, governmental agencies and other organizations (Luken and Navratil, 2004). As of February 2012, a total of 54 NCPCs were already in operation in 47 countries, organized to promote the dissemination of CP concepts and practices in industries.

The CP model is considered as an approach based on a set of more preventive techniques to achieve environmental benefits (Berkel, Willems and Lafleur, 1997). Thus, the application of its concepts and techniques in the earlier stages of the production process would make the effort of reducing environment impacts more efficient. The results of their implementation in later stages of the production process tend to be more limited either in terms of resource saving or in terms of emission reduction. Several articles that present case studies on implementation of CP have found that the main motivation for adopting this approach has been the need to reduce pollution at a lower cost (Fresner, 1998; Moors, Mulder and Vergragt, 2005; Frondel, Horbach and Rennings, 2007). The issues of process rationalization and of reduction of natural resources consumption are also contemplated in the CP approach, but only either as a consequence or as a secondary objective in the search of environmental efficiency.

Conclusion

Before making your own prosthesis, it is desirable to study the existing devices, methods of their assembly, methods of control. View the sites of existing companies that are engaged in prosthetics. Using this information to make the device functional.

3D modeling and printing greatly facilitate the task of the engineer in the manufacture of the product. Also, using 3D printing technology, the cost of the prosthesis decreases at times, which is a solution to one of the main problems in this area.

In the course of this work, the simplest bionic prosthesis was developed. While making it, I ran into a number of problems, some of which were solved and some ideas would be implemented in the future.

In the mechanical part of the prosthesis there are problems with the smoothness of the fingers, in the future I plan to use bearings to solve this problem. There is also a problem with the use of flexible material instead of hard joints to ghost fingers in motion. Fingers are not fixed.

In the study of the sensor of muscle activity, it was found simplicity of its operation (the only minus two-channel power for the board). However, Muscle Sensor v3 Overview is very difficult to use for multifunctional prosthetic control. As for me, the sensor is very capricious and unstable to noise.

Servomotors which I used are quite powerful but require a lot of power as well as space. In the future, you can use small motors with a gearbox and for feedback, set the potentiometer at the bend points.

In the absence of feedback between the prosthesis and the consumer, it is impossible to determine the degree of compression of the fingers without visual contact. For feedback of this kind, I plan to use small vibration motors and pressure sensors on the finger tips.

To manage this system, software was developed based on the Arduino controller. The controller will suit any, my choice was Arduino because of its ease of use.

In general, the work was successful, more functionality and accuracy of the device was planned, but all problems will be corrected in the future.

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