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Smart Materials and Their Application in Robotic Hand Systems: A State of the Art

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ABSTRACT

The use of soft robotics and smart materials for the design of devices that help the population in different tasks has gained a rising interest. Medicine is one of the fields where its implementation has shown significant advances. However, there are works related to applications, directed to the human body especially in replacement of devices for the upper limb. This document aims to explore the state of the art relating to the study of soft robotics, the implementation of smart materials, and the artificial muscles in the design or construction of hand prostheses or robotic devices analogous to the human hand.

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1. INTRODUCTION

Soft robotics is an emerging science that starts from the principles of classical robotics, and this is integrated with the need to achieve greater flexibility and adaptability in specific tasks (Nurzaman *et al*., 2013).

This field is based on unique, flexible, and intelligent materials adapted to bio-inspired forms. Among the most worked ones, there are the octopus tentacles, the elephant trunk, the mammalian tongue, and the starfish (Guanjun *et al*., 2018).

On the other hand, medicine is considered as one of the main areas of application of soft robotics. One of its branches and high research potential is prosthetic designs, specifically hand prostheses; we acknowledged to the constant search for the amputee in recovering the functionality of the lost member.

The human hand is the pillar of the human body in manipulating objects. It is considered the end effector of the body from the kinematic point of view. Throughout the evolution of conventional robotics, prosthetic designs that adapt to the required activity have also emerged, from the ability to grip heavy and robust objects to lighter and more delicate tasks.

In the works that integrate soft robotics with prosthesis design, the use of smart materials is considered as part of the actuator system of the hand prosthesis because the properties of these materials allowing obtaining plastic deformations and return to the initial values with the application of an external stimulus (Li *et al*., 2017). This feature provides excellent versatility when designing. Thus, the concept of artificial muscle, which seeks to be integrated into a mechanical system and fulfills the functions of this organ in a human hand, comes in this context (Ramirez, 2016).

The classification of smart materials that can be implemented as artificial muscles or can be used in a hand prosthesis mainly shapes memory alloys (SMA), electroactive polymers, magnetostrictive and electro-rheological materials. One of the challenges in using these materials is in the control process because they present physical properties that vary over time. In general, self-sensing techniques are used to control their behavior in addition to the combination of different classical control systems (Rubiano, 2016; Doroudchi and Zakerzadeh 2017).

This review aims to search and analyze the information available in databases related to the development of hand prostheses or robotic devices that fulfill their function using intelligent materials, either in their structure or in an application such as artificial muscle.

The document is divided into sections as follows. The first section shows a theoretical introduction to the topic. The second section shows the systematic description carried out in the search for the information. The third section shows the taxonomy of the information collected in the previous literature. The fourth section makes a theoretical compilation of the significant advances in the field. The fifth section shows the analysis and the discussion of the information, and the sixth section concludes the article.

2. METHODS

To create a systematic review, it is necessary to establish a work methodology that clarifies and simplifies the research's search and synthesis process. It is contemplated in three phases: Planning, Execution, and Reporting.

The planning phase contemplates identifying the topic or problem to be investigated, generating the questions that should be solved, and the search equation's inclusion and exclusion criteria, which give

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rise to the creation of the search equation to start with keywords.

The execution process is reflected in applying the search equation in the different selected databases and, with the information collected, filtering the results obtained by implementing the modified PRISMA selection criteria, as shown in the next section.

Finally, the report of the result obtained in the search process is presented, taking into account the relevance of the investigation and its impact.

2.1. Planning and Execution

Formulating the systematic review begins with the definition of the area of knowledge to work. For this case, the theme focuses on the study of soft robotics implemented in support systems for the human body, specifically smart materials in hand prosthesis systems.

From this definition, the search process begins, starting with the questions that seek to solve this research and the identification of the inclusion and the exclusion criteria that support the information filter.

This research's questions are related to the development of the study of soft robotics, the necessary materials, and their potential application in support systems for the loss of upper limb.

- What material can integrated for this use in soft robotics into human support systems?
- What characteristics should a soft robotics mechanism have to become a support system for losing the human hand?
- What mechanisms can be implemented as prosthetic hand systems?

The academy's role is sought in this area of research to know the main areas of knowledge involved. In previous related studies (Ramirez, 2016), some of the smart that meet the requirements for implementing a prosthetic system have been established. However, it is necessary to update the information collected to know the research trend. Defining the search for hand prosthetic systems through the application of soft robotics techniques and intelligent materials is pertinent to know the mechanisms or the mechanical systems that make the implementation possible.

2.2. Inclusion and Exclusion Criteria

Taking into account the definition of the research problem, the inclusion and the exclusion criteria are considered as follows:

a) Inclusion Criteria:

- Studies published between 2014 and the present
- Studies in different languages
- Publications of the following types: Articles, Conferences and Books (or chapters)
- Studies related to hand prostheses showing soft behavior

b) Exclusion Criteria:

- Publications outside the established time range
- Studies related to physical rehabilitation for hand injuries
- Studies focused exclusively on the physical properties of materials
- Characterization of materials without explicit application

3. SYSTEMATIC REVIEW

The information search process begins with recognizing the Scopus and the Web of Science databases as sources. In both databases, multiple searches were carried out, establishing specific words that should be present in the title, the abstract, or the keywords of the articles. These have been established in English. The words are:

- "Hand Prosthesis"
- "Prosthetic Hand"
- "Soft Robotic"
- "Artificial Muscle"
- "Smart Materials"

The last refinement implements four keywords and the same AND operator since it includes two different words, "Hand Prosthesis" or "Prosthetic Hand," like this:

- "Hand Prosthesis" OR "Prosthetic Hand" AND "Artificial Muscle" AND "Smart Material"

According to one of the search's exclusion criteria, the search is restricted by the time of publication, considering only the articles published in the range from 2014 to the present.

3.1. Information Analysis

Performing the search in the Scopus and Web of Science databases, the number of articles found is compared without any refinement (only the year of publication), (see **Table 1**). The keyword with the highest number of results is "Smargtt Material" since it refers to all the developments that have been carried out with the different types of material, regardless of whether they are useful in this application.

The systematic review's construction process has found out that two terms that present similar concepts. Thus, "Hand Prosthesis" and "Prosthetic Hand" are treated independently.

In **Table 1**, it can be seen that for the case of "Prosthetic Hand" in Scopus, 5562 results have been obtained while in Web of Science, only 410 results have been obtained. The difference between the numbers of the results obtained in both databases can be verified by comparing the other keywords' searches, where the WOS database presents fewer results. In the next step, the selected keywords are integrated into the search equation, which constitutes the last refinement before the search. These results are shown in **Table 2.**

For the analytical and the bibliometric process of the collected information, only the Scopus database results are considered due to the ease in the bibliometric analysis that the platform presents. This systematic review process is presented in **Table 3** and **Figure 1** as well as **Figure 2**.

Table 3 presents the comparison of the areas of knowledge involved in the research. The engineering area is the one with the most significant presence in the study. The research related to medicine is almost not involved in this context. In addition, the increase in the number of published documents can be observed, information that is corroborated in **Figure 2**.

Table 1. Results.

Keyword	Total Scopus	Total WOS
Prosthetic Hand	5562	410
Hand Prosthesis	2839	143
Soft Robotics	12168	2092
Artificial Muscle	11168	791
Smart Material	78920	840

Table 2. Last refinement.

Keyword	Total Scopus	Total WOS
"Hand Prosthesis" OR "Prosthetic Hand" AND "Artificial Muscle" AND "Smart Material"	204	168

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The comparison of the type of publication, (see **Figure 1)**, shows that the majority of documents are scientific articles followed by conferences or Proceedings.

Figure 2 shows the variation of publications per year, displaying the significant increase in the number of posts as time progresses. In 2020, most of the publications are presented. Hence, **Table 4** presents some of the studies found this year, presenting the objective sought in each document.

In **Table 4**, there is a variety in the types of materials found, as well as the main objectives to be achieved, showing that one of the common objectives is related to the need for research to understand the characteristic behavior of this type of materials. In addition, the material that presents more analysis is the shape memory alloy, due to the great potential of their physical properties to the applications of support to the human being.

With the information collected, network maps have been constructed using the VOSViewer© tool. **Figure 3** shows the co-occurrence map of the search for the keywords "Hand Prosthesis" OR "Prosthetic Hand" AND "Artificial Muscle" AND "Smart Material".

Although they present variations in the recurring words, the previous figures show common keywords, such as Robotics, Biomimetics Actuators, SMA, Prosthetic, Polymers, Artificial Muscle, among others. The previously analyzed information does not have any filtering. In order to carry out this process, an information classification system, the PRISMA model, has been implemented.

Table 3. Publications by year and field.

Year/Area	Engineering	Computation	Materials	Medicine	Total
2014	9	6	6	0	13
2015	14	10	6	0	17
2016	15	4	9	2	17
2017	22	15	15	0	28
2018	23	19	15	2	32
2019	27	18	15	2	40
2020	28	24	14	3	42
2021	19	8	11	0	25

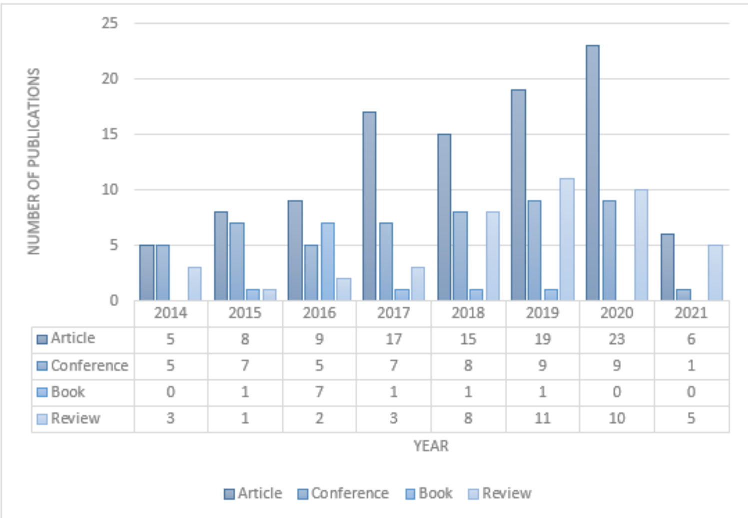

Figure 1. Types of publications.

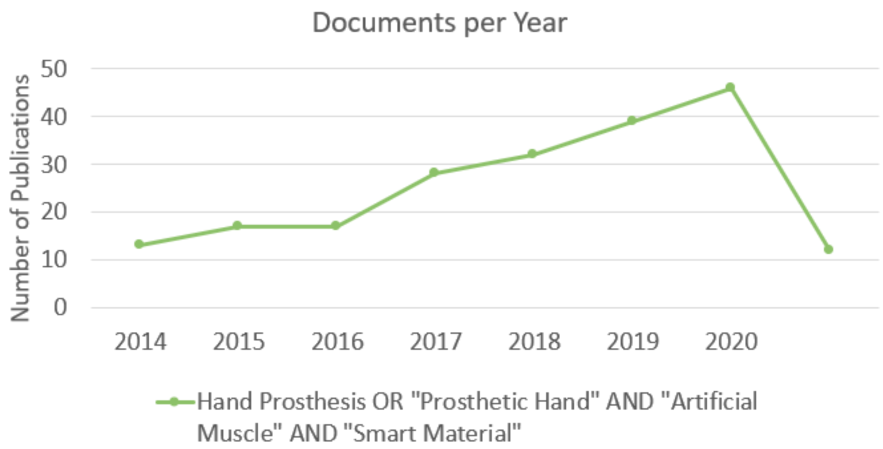

Figure 2. Number of publications per year.

Table 4. Published papers during 2020.

Material	Paper's target	Type of Publication	Reference
TPU	Control of soft robotic finger	Conference	(Tawk *et al.*, 2020)
	Variable stiffness robotic gripper	Article	(Liu *et al.*, 2020)
	SMA characterization	Review	(Vasudha and Uma Rao, 2020)
	New soft hand prototype	Article	(Simone *et al.*, 2020)
	Artificial muscle to replace a motor gear mechanism	Article	(Park *et al.*, 2020)
	Actuator by jellyfish robot	Article	(Almubarak *et al.*, 2020)
	Artificial muscle with variable stiffness	Article	(Yin *et al.*, 2020)
	Fabrication of a smart finger	Article	(Jin *et al.*, 2020)
SMA	Framework for the development of artificial muscle	Conference	(Castiblanco *et al.*, 2020)
	Accurate position control	Article	(Abdullah *et al.*, 2020)
Liquid Elastomer	Control of soft gripper prototype	Article	(You *et al.*, 2020)
	Pneumatic actuator for two fingers dexterous robot	Article	(Lin *et al.*, 2020)
	3D printed bending device modeled using FEM	Conference	(Tawk *et al.*, 2020)
	Trends in soft pneumatic robotics	Review	(Guan *et al.*, 2020)
	Proprioceptive information	Article	(Jung *et al.*, 2020)
Pneumatic	High load Gripper	Article	(Li *et al.*, 2020)
Twisted Elastomer	Artificial Muscle	Article	(Wang *et al.*, 2020)
DC Motor	Design of high velocities prosthetic finger	Article	(Yoder *et al.*, 2020)
Piezoresistive	Strategies of self-sensing	Review	(Duan *et al.*, 2020)
Polyethylene	Light driven artificial muscle	Article	(Bhatti *et al.*, 2020)
	Lineal and rotational deformations	Article	(Bloom *et al.*, 2020)
IPMC	Modeling and control of IPMC	Conference	(Histed *et al.*, 2020)
TCP	Control system for twisted and coiled	Article	(Ochoa *et al.*, 2020)

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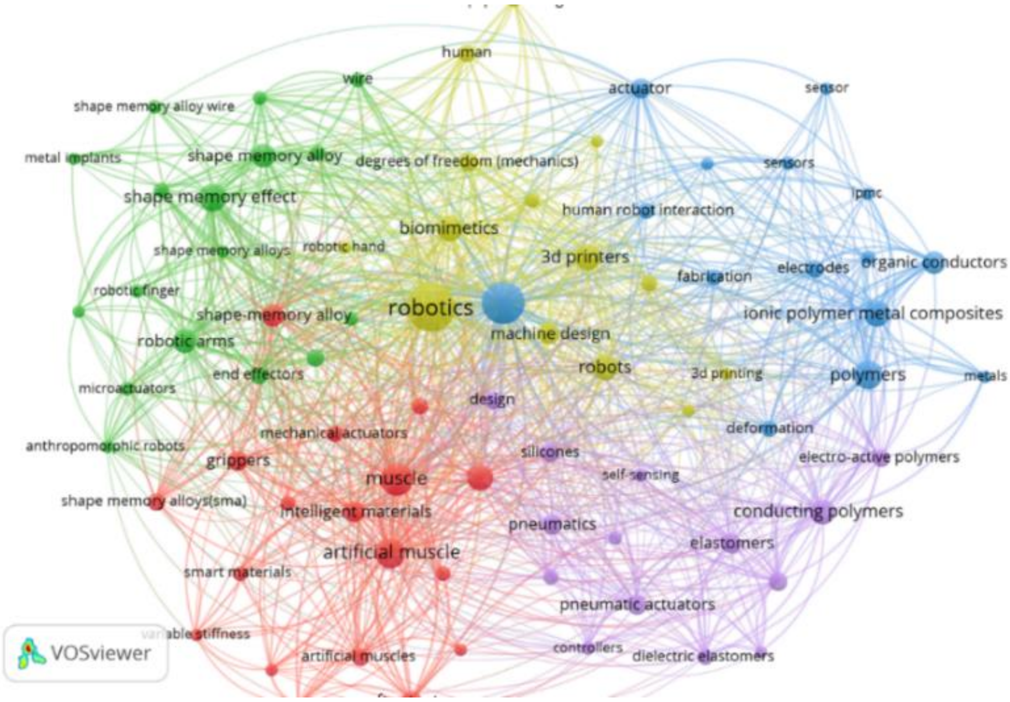

Figure 3. Network map.

4. ANALYSIS INFORMATION COLLECTED

After searching for the general information, the classification system of the documents that are ultimately useful in the investigation is executed. For this case, the PRISMA criterion has been used for selection.

Within the information filter process, two stages of fast reading and exclusion by relevant topics are considered, presented in detail in **Table 5**. The compilation of the criteria is summarized in **Figure 4**, where 204 documents have been collected in the consulted databases, and ten specific documents classified from previous searches, six duplicate documents have been found.

After reading the abstract and the keywords, 49 documents have been discarded. Although they mention hand prostheses, they are not found in their study.

There have been 99 documents left for a full reading. By reading the introduction, it has been possible to discard 46 more titles. Although they have been related to the research, they do not provide meaningful information to the objective. At the end, 79 documents contribute to the search for current developments.

5. DEVELOPMENT

In order to carry out the investigative exploration related to the use of soft robotics techniques in hand robotic systems, this section is divided in a way, allowing visualization of the different factors that influence their study.

It is possible to classify the information collected. **Figure 5** shows the taxonomic classification of the collected documents. The study is divided into two main groups: the developments framed in classical robotics and the studies of soft robotics.

By taking this classification into account, it is necessary to address and understand the subject matter related to classical robotics, which is composed by those devices to support the human being. It is not only in the medical field but also in daily tasks, representing a risk. The combination of mechanical devices plus control systems allows improving the quality of life of people (Khairudin *et al*., 2020). Although it uses techniques, procedures, and materials different from soft robotics, it can provide effective solutions with a bio-inspired and flexible approach.

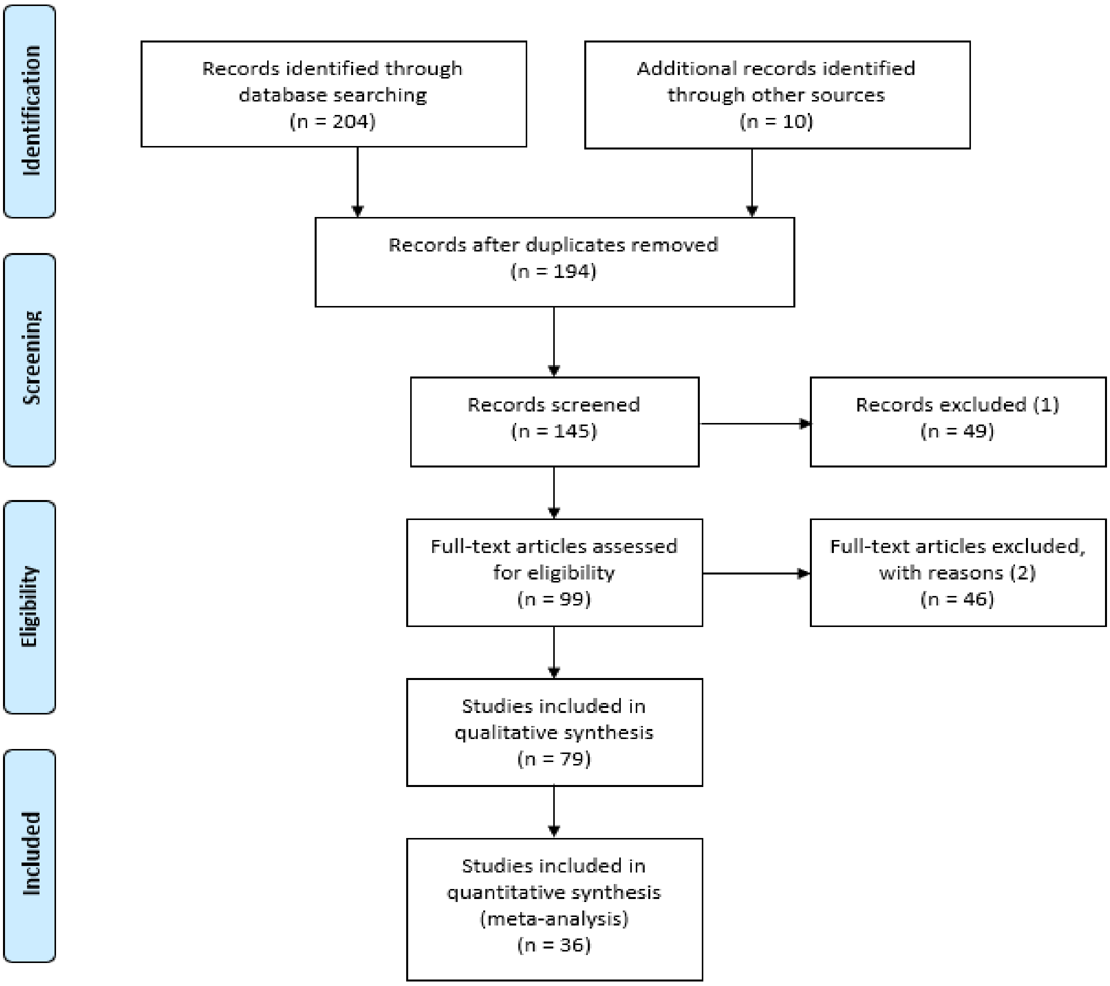

Figure 4. PRISMA criterion.

Table 5. Systematic review filters.

Filters Review
(1) First filter exclusion: Studies focused on smart material's physical and mechanical properties; studies focused exclusively on the human body's physiological behaviors.
(2) Second filter exclusion: Control processes without focus on prostheses, material behaviors in the implementation of artificial muscles.

5.1. Applications in Classical Robotics

Although the research is directed towards searching for soft robotics applications, documents related to classical robotics that seek similar objectives in the implementation of techniques that allow greater skill and dexterity in a handheld robotic device have been found out.

These studies are not included in the original search classification. However, they represent the versatility that can be found by combining or implementing simple robotics concepts. In **Table 6**, the classification according to the purpose of some studies, the materials implemented, and their differentiating factor is shown.

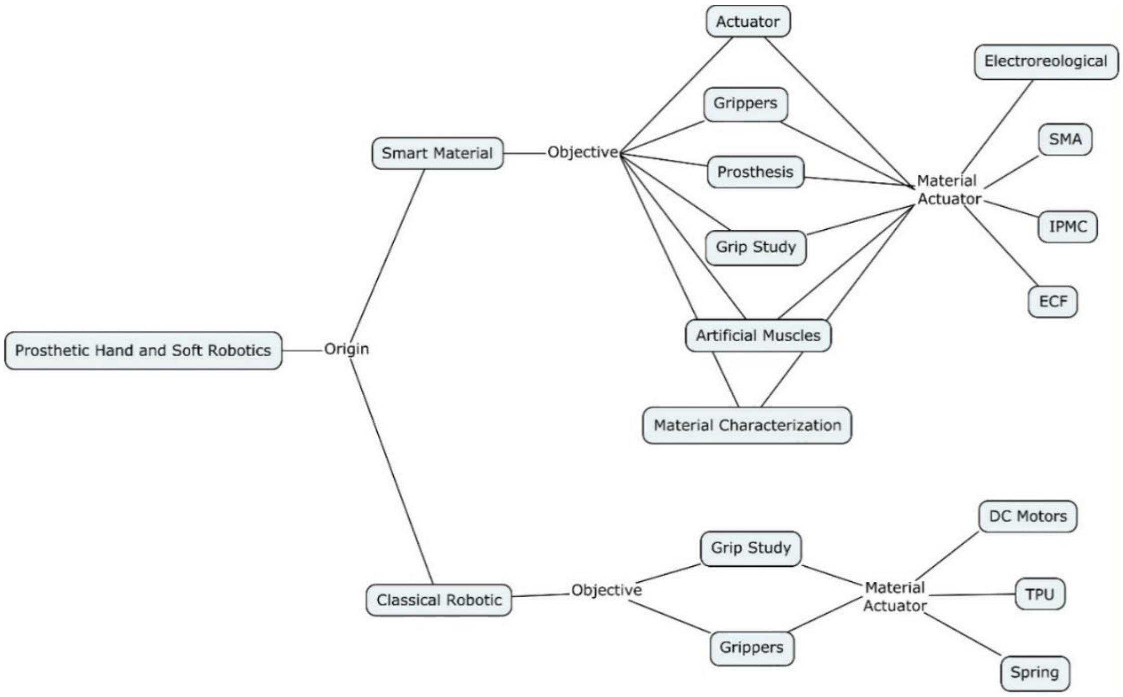

Figure 5. Taxonomy.

Table 6. Classic robotics.

Reference	Autor	Publication Year	Type of Document	Mechanism	Material
(Tawk *et al.*, 2019)	C. Tawk et al	2019	Conference	Hand Actuator - TPU 3D printed	TPU
(Rahman *et al.*, 2015)	N. Rahman et al	2015	Conference	Robotic Hand - Rotation in different axes	DC Motors
(Deimel and Brock, 2016)	Deimel R. Brock O	2016	Article	Robotic Hand - Dexterous grasping	Pneuflex
(Li *et al.*, 2020)	Li H et al	2020	Article	Artificial muscle configuration - Pneumatic gripper to support heavy loads	Pneumatic
(Lau andChai, 2012)	Lau C. Chai A	2012	Conference	Anthropomorphic robotic hand - Specific gripinig task, 16 DOF	Pneumatic
(Li *et al.*, 2019a)	Li C et al	2019	Article	Robotic hand - Soft modulation	DC Motors

5.2. Applications in Soft Robotics

Robotics is a field of engineering that has been worked on since the 50s. The technologies that are being worked today are quite complex and robust in terms of control, speed, and movement systems. However, all of the above is under the assumption of rigid joints for its modeling and implementation.

Recent advances speak of modifying the material with which robots built characteristics that are not possible with the use of rigid materials, , in order to achieve tasks that are more specific with a higher level of interaction and compliance with the work environment (Laschi and Cianchetti, 2014). Soft robots use mechanisms with more skill than conventional ones; this is shown in **Figure 6** (Trivedi *et al*., 2008).

In nature, there are many examples of structures that can be implemented in a soft robotic system, mainly hydrostatic muscle systems that can be found in mammals, fish, and plants, among others. In order to carry out the design and the implementation of a soft system, it is necessary to understand these structures' morphology and functionality in nature.

The documents consulted are related to the implementation of soft robotics techniques showing different objectives.

Considering the classification of documents that focus on soft robotics, the turn should classify these documents, which present different factors that can be taken advantage of. Below, the classification according to the material used and the different aspects to consider related to its behavior of the material can be found.

One of the most common objectives in the studies consulted is related to the material's behavior or physical response. The authors use the implementation in a robotic finger or hand as a verification technique, since it represents a visual and immediate way of observing the material's operation, mainly to verify precision grip capabilities. This is due in part to the versatility of the materials and its novelty in the scientific field.

5.3. Smart Materials

An intelligent material is a type of raw material that seeks to mimic the ability of nature by reacting to different external stimuli. This is achieved by reversibly varying its physical properties, including principles of adaptation and feedback. Smart materials are sorted by their physical foundation: piezoelectric, electroactive polymers, shape-memory materials, magnetic effect materials, magnetostriction, or halochromia.

Each material has different characteristics, mainly in terms of deformation and stresses (Lagoudas, 2008). In order to define which materials are suitable for searching for an artificial muscle, the stiffness to which the material should be subject is considered (Ramirez, 2016).

In related literature, the most of the used materials are electroactive polymers and shape memory alloys. Therefore, this report focuses on these two materials.

5.3.1. Electroactive polymers

The electroactive polymers are types of polymers that react mechanically to electrical stimulation. They are constituted from an elastomeric and dielectric material sheet, and sheets with a conductive electrode are located on each face. The material converts an electrical force into mechanical movement. These materials can withstand high deformation levels when subjected to high forces, resistance to fracture, and dampen vibrations. One of the most recognized materials in this group is IPMC since its molecular structure makes it an excellent medical application. (**Figure 7**) (Shahinpoor *et al*., 1998; Koo *et al*., 2009).

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5.3.2. Shape memory alloys

Shape memory alloys are materials that can recover their original shape by varying their temperature, in addition to other unique behaviors (Wheeler *et al*., 2016). This material undergoes a reversible change in its crystalline structure, achieving changes in its phases. The first one is a high-temperature phase called austenite, and the other one is a low-temperature phase is called martensite **Figure 8** represents the passage of the material through each phase, depending on its temperature and the stress it is subjected to (Lagoudas, 2008).

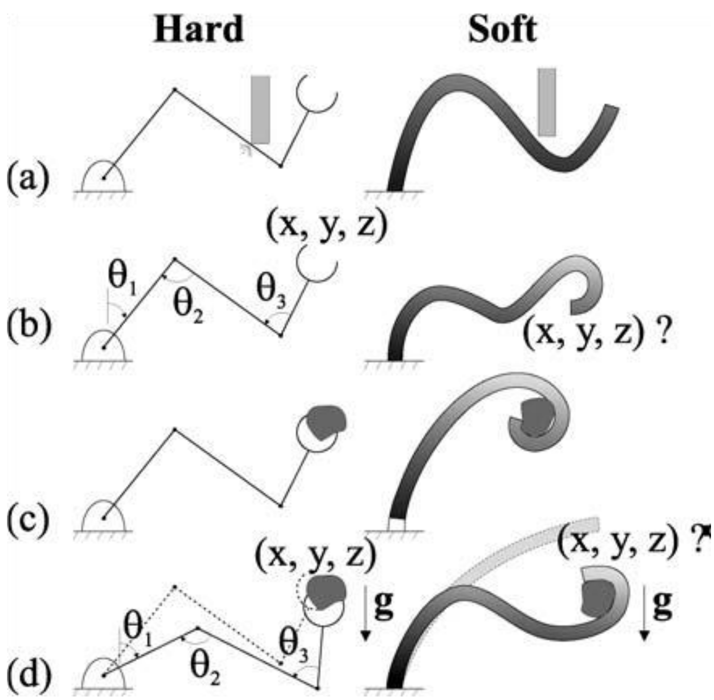

Figure 6. Soft Robotics: a) Dexterity b) Position Sensing c) Handling and d) Loading (Trivedi *et al*., 2008).

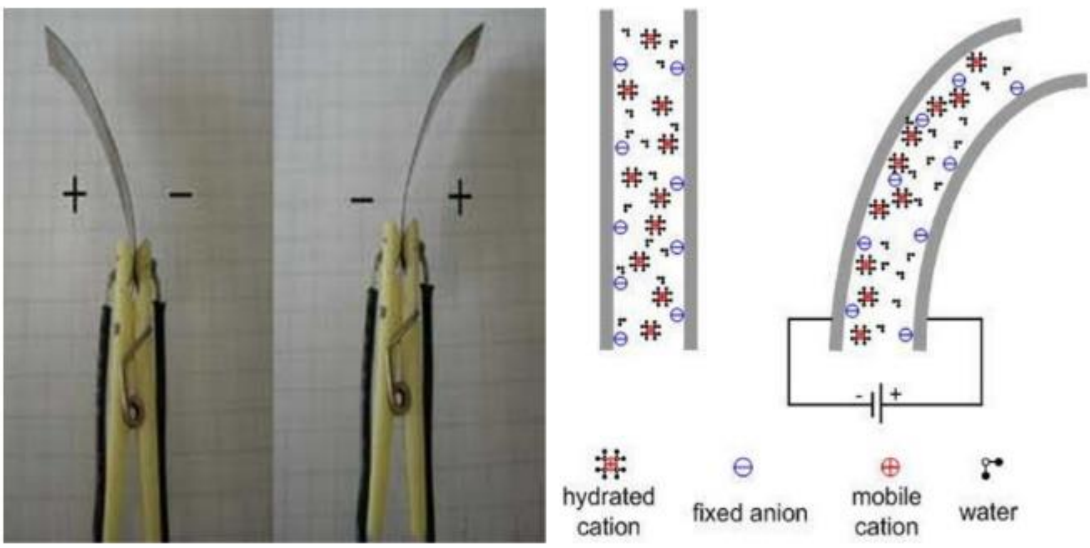

Figure 7. Particle behaviour according to IPMC polarization (Koo *et al*., 2009).

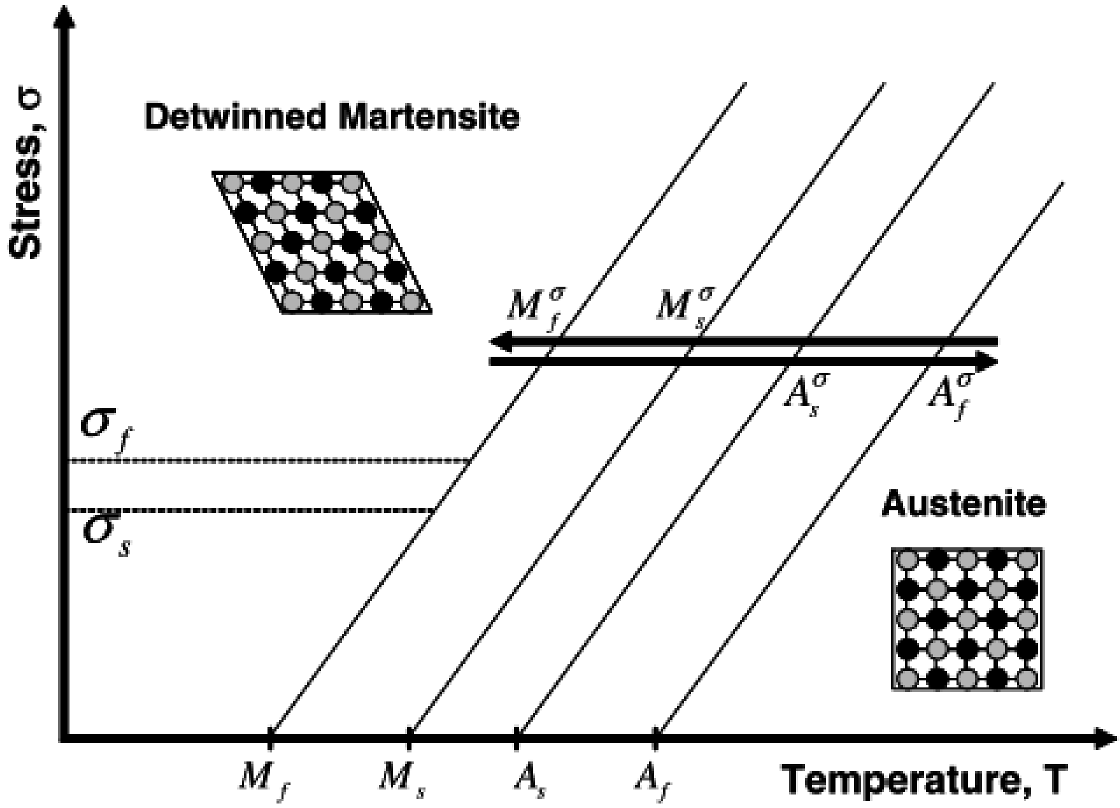

Figure 8. Phase transformation temperature under the effect of mechanical load (Lagoudas, 2008).

5.4. The Hand

The objective of this document is by collecting the latest developments relating to prosthetic or robotic handheld devices.

5.4.1. Human anatomy: The hand

The human hand is a complex adaptive mechanism that plays a fundamental role in human interaction and basic gripping and sensing tasks. It consists of a palmar area and five fingers, as shown in **Figure 9** (Taylor and Schwarz, 1955; Feix *et al*., 2016).

The human hand consists of 27 bones, eight located in the carpus or wrist, five metacarpals, and 14 phalanges. There are several types of joints: Metacarpophalangeal (MCP), Carpometacarpal, and Interphalangeal (Proximal PIP and DIP Distal), and his muscular system is made up of intrinsic and extrinsic muscles.

Mechanically, in (Ramirez, 2016), a compilation of information related to the rotational limits of each joint is carried out.

The primary function sought to restore with a prosthesis is the grip capacity, which according to the literature, is divided into power and precision grips.

This information is presented in (Feix *et al*., 2016) and (Cutkosky, 1989), where the types of grip and their mechanical characteristics are classified in detail.

5.4.2. Human anatomy: The muscle

The human muscle is a contractile organ, it constitutes 40% of the body weight, and it is in charge of generating movement. It has blood, and nerve irrigation that allows it to generate contraction and relaxation movements. This is made of a series of fibers located in an aligned way, and for this case, the skeletal muscles, which perform the

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movement using the bone system as support, are studied. The muscles of the hand can be extrinsic or intrinsic, depending on their location. The extrinsic muscles' location is in the forearm, and the tendons transmit movement. They are responsible for giving mobility to the hand's phalanges. The focus of the research is directed towards the flexion-extension movement that these muscles generate.

5.5. Artificial Muscles

The study of artificial muscles seeks to create a device capable of emulating the behavior of a human muscle, since, being the organ of the human body responsible for generating movement, its applications are widely distributed. Soft robotics seeks to emulate these systems, in conjunction with the implementation of intelligent materials.

The first mechanical model of a muscle developed by (Hill, 1950), which consists of the muscle's mechanical description to show its elastic behavior, represents the muscle in series with the tendon. The latter presented as a viscoelastic system. Different authors have modified this original design and have led to new research that has evolved to achieve very similar systems (Hatze, 1978; Zajac, 1989; Winters, 1990; Winters and Woo, 1990; Millard and Uchida 2013).

6. INFORMATION COLLECTED

After presenting the analysis of the search for information related to the development of prosthetic systems implementing smart materials, this chapter presents, in a structured way, the compilation of the latest works that have been developed.

6.1. Application in Actuator System

Considering the research carried out, **Table 7** is constructed. The compilation of the studies related to actuator systems is carried out, especially the ones that contemplate the development of artificial muscles through different techniques.

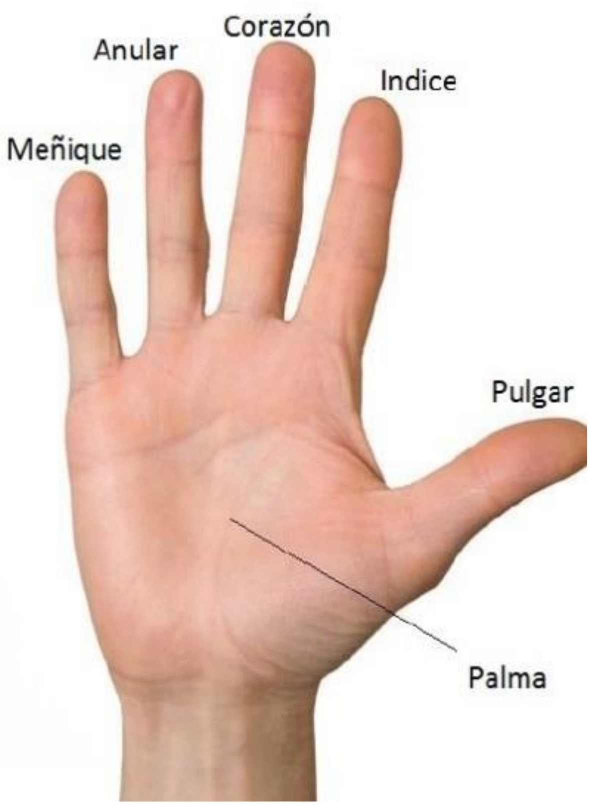

Figure 9. Human hand.

Although these are not directly related to prosthetic systems, these are potentially applicable jobs. **Table 7** shows the information on each document for identification, such as year of publication, type of publication (Article, Conference or others), type of material, and specifically, a brief description of this objective and its particularities. With the information collected, It is possible to carry out an analysis process of the compiled information.

More specifically, this section seeks to know the advances in applications to hand prostheses through soft robotics implementation. The first classification is evidenced in the previous section, where research related to artificial muscles and similar actuator systems is shown.

In the information classification process, the type of application, robotic hand, prosthesis, or finger is presented, and the type of material used is presented in a simulated way. **Table 8**, there is a compilation of the study and the identification mentioned.

Table 7. Actuator systems.

Reference	Type of Document	Material	Objective	Descriptive Approach
(Hamburg *et al.*, 2016)	Article	SMA	Artificial Design Muscle	Hydrostatic muscle of the octopus, contraction and elongation in water
(Aw and McDaid, 2014)	Article	IPMC	Mechanical Model	Current biomedical applications and future challenges
(Jaber *et al.*, 2015)	Article	SMA	Mathematical Behavior	Finite element analysis for artificial muscle
(Yip and Niemeyer, 2015)	Conference	SCP Nylon	Artificial Muscle with Polymer	Mathematical model of coil actuator, low cost application
(Carrico *et al.*, 2016)	Book	IPMC	Mathematical Model	RC circuit implementation, mathematical model and control
(Saharan *et al.*, 2017)	Article	TCP	Weareble Device with Artificial Muscle	Wearable 3D handheld device, simulation grip with different sizes and shapes
(Karami and Tadesse, 2017)	Article	TCP	Modeling Artificial Muscle	Mathematical model of artificial muscle, thermal, electrical and mechanical pnemomenal
(Yip and Niemeyer, 2017)	Article	SCP	Artificial Muscle Actuator	Mathetical model of Material in quick response
(Almubarak and Tadesse, 2017)	Article	TCP	Superficial Artificial Muscle	Superficial pneumatic muscle application
(Bilodeau *et al.*, 2018)	Conference	Silicon	Actuator Design	Soft integration Pneumatic actuator, FEA analysis
(Xiang *et al.*, 2018)	Article	SMA	McKibben Muscle	Artificial muscle with McKibben properties
(Lee *et al.*, 2019)	Article	SMA	Actuator Design	Tendon system
(Cho *et al.*, 2019)	Article	TCP	Musculoskeletan Actuator	Opposing wire configuration
(Chen *et al.*, 2019b)	Article	Graphene	Self Sensing	Self sensing sheet with piezo and thermoresistive propierties, body movement measurement
(Li *et al.*, 2019c)	Article	Silicone	Actuator with Windind effect	Pneumatic actuator based on air flow, reaching objects of different sizes and shapes

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Table 8. Robotic hands.

Reference	SMA	IPMC	Other	Artificial Muscle	Robotic Hand	Prosthetic Hand	Finger	Observations
(Chattaraj *et al*., 2014)		X			X			Natural in grasp
(Engeberg *et al*., 2015)	X						X	Antagonistic control finger
(Wu *et al*., 2015)			Nylon	X			X	Circulating hot and cold water
(She *et al*., 2015)	X		PZT		X			Grasping irregular objects
(Huang *et al*., 2015)					X			Support in rehabilitation
(Dilibal and Engeberg, 2015)	X						X	Execution speed
(Ahmadi *et al*., 2015)	X				X			Combination soft materials with 3D printing
(Andrianesis and Tzes, 2015)	X					X		Control grasping daily task
(Kim *et al*., 2016)	X						X	Driven wire tendon
(Tao and Gu, 2017)			SPA				X	Self-sensing actuator
(Wu *et al*., 2017)			Nylon	X		X		Silmilar to human hand
(Wright and Bilgen, 2016)	X					X		Biomechanical analysis
(Wang and Ahn, 2017)	X				X			Different shapes objects
(Simone *et al*., 2017)	X					X		Concept model gripping
(Ramirez *et al*., 2017)	X			X			X	Design Methodology
(Maffiodo and Raparelli, 2017)	X			X			X	Manipulation of small objects
(Ozkan *et al*., 2017)	X						X	Anatomic analog model
(Chen *et al*., 2018a)	X	X		X	X			Support with pneumatic
(Silva *et al*., 2018)	X						X	Fuzzy control
(Chen *et al*., 2018b)	X				X			Modular 3D design
(Atasoy *et al*., 2017)		X					X	Optimization natural muscle
(Maroti *et al*., 2019)	X					X		Additive manufacturing

Table 8 (continue). Robotic hands.

Reference	SMA	IPMC	Other	Artificial Muscle	Robotic Hand	Prosthetic Hand	Finger	Observations
(Liu *et al.*, 2019)	X				X			Control reinforcement learning
(Truby *et al.*, 2019)			Ionogel				X	Somatosensory feedback
(Simone *et al.*, 2019)	X						X	Control dynamic response
(Ramirez *et al.*, 2019)	X				X		X	Soft epicyclical mechanism
(Li *et al.*, 2019b)	X					X		Design without sensor
(Chen *et al.*, 2019a)			Piezo				X	Compact and high precision
(Liu *et al.*, 2020)	X				X		X	Variable stiffness
(Jin *et al.*, 2020)	X					X	X	Hybrid composite
(Yin *et al.*, 2020)	X		Nylon	X			X	Variable stiffness

7. DISCUSSION

It starts from the clarification that within the classification of information collected in various groups, conventional robotics techniques to obtain "soft" solutions and that in this study are called cases of Conventional Robotics. With the information collected, it can be established the following.

7.1. Conventional Robotics

Regarding the studies found related to soft robotics applications, these ones are mostly focused on pneumatic systems that can provide operating ranges similar to those provided by smart materials. Other formulations are:

- The development of research framed in the study of new bio-inspired and flexible skills using materials belonging to conventional robotics represents a design challenge since innovative solutions are required for their use.
- By combining of different materials or techniques, it is possible to achieve these solutions. However, this can generate difficulties in their preparation and implementation. It is always important to consider factors such as costs, available resources, and necessary equipment.
- Some studies and investigations have carried out the combination of techniques, implementing classic and soft robotics in the same device, enhancing the qualities of each technique and material, and achieving efficiency in the objectives set.
- The main objective of the collected studies is the search for the improvement of skills, specifically the grip and the precision of robotic or prosthetic handheld devices.

7.2. Soft Actuation and Artificial Muscle

In the collection of information related to the applications of actuator systems, artificial

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muscles, and the behavior of the material, without considering the robotic hand systems, it can be established that:

- The predominant type of publication is the scientific article typology. Given the conditions of the subject, it allows ensuring the reliability of the information expressed.
- The most studied materials are alloys with shape memory or SMA and Ionic Polymer Metal Composites or IPMC. This is to their acquisition and use strategies, which can become more superficial than in other types of smart material.
- The majority of the related studies that present an artificial muscle in this study consider its application in a human support system or rehabilitation.
- The studies contemplate the development of mathematical models to carry out the computational verification of the actuator models. The majority of these mathematical models are based on a muscle's mechanical model, i.e. the Hill model (Hill, 1950).

7.3. Robotic Hand Systems

The central point of the research is knowing which are the most recent studies and the research related to the development of hand robotic systems. In order to centralize and organize the information, **Table 7** is constructed. In the information classification process, several filters have been made after implementing the PRISMA methodology. This selection has been based on the studies' objectives.

In the first place, those studies that deal with conventional robotics techniques, whose compilation is shown in **Table 6**, have been excluded.

The second compiled includes excluding those works related to intelligent materials and artificial muscles, but without a direct application in hand robotic systems. These documents are shown in **Table 7**. For the previous cases, the respective analyses are already present.

After this filtering, 35 documents have been finally selected (see **Table 8)**, and the co-occurrence map is shown in **Figure 10**.

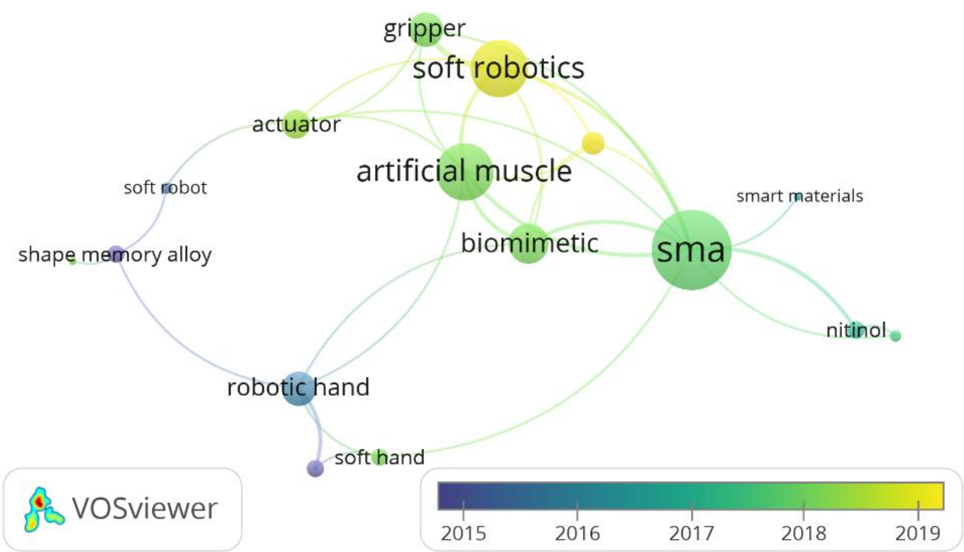

Figure 10. Final network map.

The map in **Figure 10** shows that the main word covered by the research is SMA, which refers to shape memory alloys, followed by artificial muscles and soft robotics. The research trend is also observed over the years, establishing a study range from 2015 to the present. It is evidenced that topics such as a robotic hand had a higher impact at the beginning of the range (1983) and that at present, the most touched topic is the concept of soft robotics. Another information obtained after the construction of the table is the specific application that the investigations are looking for, obtaining that most of the studies present the design, the simulation, the prototyping, or the construction of finger systems or hand phalanges, but the construction of the entire hand is not contemplated in most studies. It can be established that:

- Most of the studies consider alloys with shape memory as a raw material. A more exhaustive study would allow knowing the reasons that drive this behavior of the research centers.
- The studies have been carried out to contemplate using different materials and performance techniques. However, no information that shows a portable prosthetic or robotic system that can be easily transported and used in different environments has been found out.
- A potential research topic is related to the search for new materials that adapt to an artificial muscle's physical properties that can be implemented in a portable hand-held prosthetic system, and that can be developed considering the location of the research center.

8. CONCLUSION

To finalize the study, it is concluded that the use of metadata analysis methodologies makes it possible to refine unnecessary information so that the documents selected have a great affinity with the search's objective. Although a filter is implemented at the time of collecting information in the databases, it has been necessary to filter the documents one by one because, although they are related to the topic, some documents do not present the desired relationship. In studies that only contemplate artificial muscles without mentioning robotic hand systems, they present their approach to the material's physical properties to be explored, especially variables such as force and stress. The study of hand prosthetic systems that implement materials other than SMA is a field of action that is emerging, representing a path in the study of new techniques, which may represent the exploration of new capabilities in a hand robotic system.

9. LIST OF ABBREVIATION

List of abbreviation is shown in **Table 9**.

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11. AUTHOR’S NOTE

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Table 9. Abbreviation list.

Abbreviate	Name
3D	Three Dimention
DC	Direct Current
DIP	Distal Interphalangeal
DOF	Degree of Freedom
ECF	Electro Conjugate Fluid
IPMC	Ionic Polymer Metal Composite
MCP	Metacarpophalangeal
PIP	Proximal Interphalageal
PRISMA	Preferred Reporting Items for Systematic Review and Meta Analysis
SMA	Shape Memory Alloy
TPU	Thermoplastic Polyurethane
TCP	Twisted and Coiled Polymer
WOS	Web of Science

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