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EXPANDING THE FUNCTIONAL ONTOLOGY IN CONCEPTUAL DESIGN

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ABSTRACT
Functional analysis represents one of the key tools for designers at a conceptual design stage. It describes a product or a problem at an abstract level allowing a clear and standard representation aimed to an effective exploration of different design alternatives (functional variants). In engineering design, the existence of a product is subjected to its function. Functional modelling helps the designer to provide an abstract, yet direct, method for understanding and representing the functions of a product or artefact.
Functional analysis however, traditionally found a lot of difficulties in practical industrial application. One reason is that it forces designers to think in highly abstract terms, contrary to their natural attitude and cognitive style. Furthermore, a long preparation is needed in order to carry out sessions of functional analysis, making the technique hard to be implemented. This situation has spurred efforts for the development of standardized dictionaries, in order to support the reasoning process.
A formal representation, in fact, is necessary to support functional modelling. A standardized dictionary of functions leads to repeatable and meaningful results from such representation. A very interesting proposal of functional basis leading to the integration of several independent research efforts into a reconciled structure has been recently published in the literature.
Unfortunately, since its aim was to describe every electro-mechanical function with a minimal number of verbs, the reconciled functional basis is pretty poor of entries. This restriction obstacles the automatic extraction of functional verbs, makes the learning period quite long, and makes it difficult to perform efficient search for functional variants.
To answer these needs a new dictionary and thesaurus of functional and structural verbs has been studied and developed. A team of mechanical engineers, economists, and experts of text mining and focused search engines collaborated for a long period in order to extract functional verbs from technical texts. We have developed a large dictionary, alongside a novel hierarchical classification, including detailed treatment of synonyms and antonyms. On the basis of this new representation, implemented in a software application tool, it is possible to rapidly map the functional tree associated to any function.
In addition to the theoretical value of this development, practical implementations are in progress. Preliminary tests have been performed in the context of patent analysis. Critical applications concern early product development in the automotive industry, supporting product development sessions.

Keywords: Functional Analysis, Functional Ontology, Patent Analysis.

1 INTRODUCTION AND STATE OF THE ART
Functional analysis evolved during the last decades, from the original proposal by Miles [1] and the first rationalization by Pahl and Beitz [2] to the attempt of the NIST [3] and the last interesting synthesis proposed by Hirtz et al. [4][5].
Functional analysis has been used to describe a product from a functional point of view. The need of objectivity and independence of the description from the author brought to the development of a standardised functional lexicon. A functional verb is defined [6] as an action able to modify one or more technical characteristics of the object of the action. In Functional Analysis [2] each function can be described using only two words: a verb and an object. This way, even the most complex product

can be divided into its functions, i.e. into a series of simple single actions described by a verbal form and the flow of material, signal or energy as the object.
In time functional analysis spread out and influenced the development of many other methods.
For example, Design For Assembly [7][8] starts from a functional approach, Quality Function Deployment or FMECA (Failure Mode Effect and Criticality Analysis) take advantage of a well structured functional analysis [9], product functional breakdown is fundamental for benchmarking, or for standardization, and hierarchical functional trees can be used to modify the product architecture [6]. Finally Functional Analysis is unavoidable in the cases of Value Analysis and Value Engineering as well as in Fault Tree Analysis where the relationships between functions are investigated [10].
More recently, functional concepts have been at the core of developments in such diverse areas as problem identification analysis (as in design by analogy [11]), product modelling [12], extraction of relevant functional information from CAD systems (Line and Steiner [13]), text translation (Cascini [16] and Neri [15]), solution generation (TRIZ [17]), radical innovation [18], conceptual design [19] and design for X as Kitamura [20] proposes.
However, so far researchers have developed systems based on small function bases, following the principle of developing a minimal set of verbs to describe every mechanical function [5]. This choice was reasonable in the context of a semi-manual use of the system. The expert would have to decide whether a particular expression should be categorized under a given functional verb in the basis. Under this condition having a small number of verbs is an advantage. The limit of this approach is that it requires lot of preparation and interpretation.
We exploited the huge potential of advanced text mining techniques in order to build a large functional database, in which each expression can be easily be categorized under a functional verb and its qualifications. The system produces abstractions by linking up the verb to his father in an iterated way, so that at the end the number of highly abstract verbs is kept to the minimum (similar to [5]), but in the context of a very large and complete functional database. It has the advantage of making the system much more flexible, user-friendly and able to accelerate the learning process.
Traditionally, functional modelling has been used more to represent the physical solution that implements a certain function, than as a creativity tool. Recently Fantoni et al [6] have pointed out that there is more than one functional way to solve a problem. A novel method, based on functional synonyms and antonyms, able to focus the designer creativity on alternative functional solutions has been presented. The method suggests the idea of a highly connected functional verbal space where there are not only strictly hierarchical or vertical relations, but also horizontal ones, and that a rich functional database should be able to fully represent both types of relations.
Therefore we decided to adopt a hierarchical structure organised in four levels (as that in [5]) but internally connected. This structure presents abstract verbs located at the first level (as the roots of a tree), while their children are at the second, grandchildren at the third one and so on. Hence the intrinsic tree-like structure of traditional functional basis proposed by Hirtz et al. [5] has been extended at the correspondent level towards an evolved interconnected structure. In fact Hirtz kept his functional base to a minimum both in the number of verbs and in that of possible relations among them, in order to facilitate the user and to make the method easier. Indeed without the aid of fully navigable graphs it could be difficult for a neophyte to approach a complex interconnected functional space. Nowadays the use of dedicated tools could allow a user to quickly surf even a functional space of some thousands of verbs variously connected.
Moreover, because of its extreme synthesis some open issues emerge from the verbal base [5]. First the same verb (*to capture*) can have multiple meanings (a. to catch something, b. to store something) has two different fathers (*to import* and *to store*). In our scheme it corresponds to have two distinct verbs *to capture1* with the first meaning and *to capture2* with the other, each with a different father. Secondly others functions are clearly referable to two distinct fathers (e.g. *to channelise* belongs to both *branch* and *guide*), that we manage by the graph structure. Furthermore, some classes (e.g.: *to convert*) contain at the correspondent level both synonyms and antonyms while others (e.g.: *to distribute*) contain only synonyms.
In our opinion this evidence demonstrates that the hierarchical tree structure has to be overcome by a matrix functional one. Any node in the matrix represents a function linked with one or more fathers, with brothers (strictly synonyms), cousins (verbs with a similar meaning) and opposites (antonyms). Data bases with relationship structures can allow the researcher to free the rigid traditional approach extending the functional tree and exploiting all the feature of this new denser structure.

Summarising, while defining a minimal set of functional verbs that span all electro-mechanical functions has a logic, there are not *logical* reasons why a functional tree should be kept small and strictly hierarchical, rather than large (at the correspondents level) and highly connected (at all levels). The direction taken in the literature has been clearly influenced by the limits of the knowledge representation and computational techniques in dealing with large interconnected graphs.
Thanks to its synthesis, we consider the reconciled functional base as the baseline for this work. It has been extended by the addition of some thousands of verbs and enriched by a series of new relations among the verbs themselves. We experienced that recent developments in text mining, graph representation and graph surfing make today possible to develop new tools that aid the technicians in learning, analysing and redesign. Some examples are shown in the case study.

In addition these developments allow to reconsider one of the most difficult issues in functional analysis, i.e. the explicit elimination of the time dimension. This feature has been strongly justified in terms of the need to distinguish between functions (i.e. final result of an action) and time sequences, leaving the latter to other representations (e.g. flow diagrams) in order to avoid confusion. This solution is perfectly adequate for many applications. On the other hand, however, eliminating time makes it impossible to represent some functions. This fact forces the designer to keep separated the logical and functional representations. We reintroduced time explicitly in the functional basis and discovered that, by treating it in an atomistic way, it is possible to obtain neat representations.

2 THE METHOD USED TO EXTEND AND ORGANIZE THE NEW FUNCTIONAL ONTOLOGY

2.1 Expansion of the functional data base

In order to expand the reconciled functional tree [5] and following a consistent practice in the literature ([15][16][17]), we started from a systematic examination of patents as a source of new verbs. 40 Patent classes (with different IPC codes) have been selected among those concerning electro mechanical systems. Three to five patents per class have been analysed by using a tailored software application tool. It automatically extracted from the patent text all the verbs, differentiating between those already existing in the functional database and the others not yet included.
Unfortunately patents contain not only functional or structural verbs [17], but also descriptive (e.g.: *to claim*, *to describe*, ..) and phraseological ones (*to work*, *to act*). Moreover the authors of patents often remove repetitions by using verbs with a shaded meaning or, especially in patents written by lawyers, very generic verbs are used to enlarge the possible claims. Therefore different kinds of verbs have been proposed within a novel definition of functional verbs (see below).
The data base used for this paper contains verbs extracted from this patent sample (n=3,000 verbs approximately); the system has then been further enlarged with the use of a technical dictionary reaching a total number of 5,000verbs.
The patent classes have been selected to be largely representative of main mechanical and control functional issues. The procedure has been based on a saturation technique: after a certain number of iterations, new verbs come mainly or exclusively from new IPC classes, rather than from new documents in the same IPC class. Therefore the construction of the basis has followed an economic principle, i.e. equalizing the marginal cost of search with the marginal value from the expected number of new verbs. Figure 1 shows this effect.
In our approach, however, the process is open ended: the functional data base is open to new verbs that can be generated using a semi-automatic uploading procedure, particularly when the extension to new technological areas is requested.
For each new functional verb inserted in the data base, also its synonyms (when two distinct verbs are totally equivalent from a functional point of view [22]), near-synonym (verbs describing a similar function) and antonyms (opposite function) have been added [24]. This way the data base grew up containing not only a set of verbs but also a series of relations among the verbs themselves.

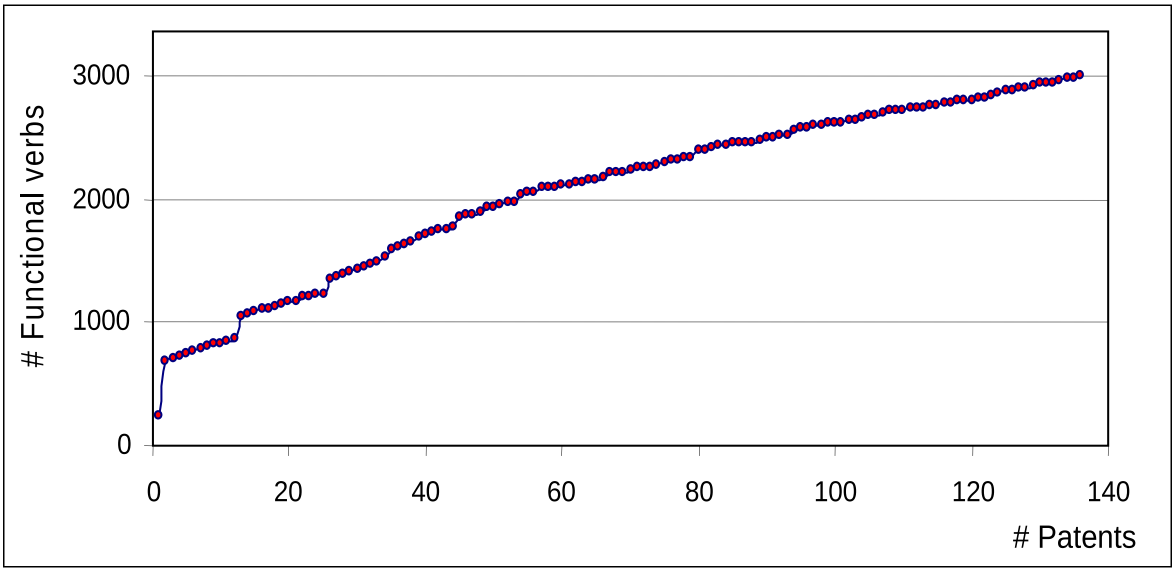


Figure 1. Number of verbs in the data base vs. analyzed patents. The curve starts from 250 verbs in the reconciled function base [5]. The leaps in the curve correspond to expansion of the functional data base obtained through synonyms and antonyms.

2.2 Classification of new verbs

Before defining the new classes of verbs it is important to underline that hereafter a novel definition of functional verb (introduced in [6]) has been adopted.

A functional verb describes an action that modifies one or more measurable technical characteristics of the object of the action. This definition differs from the standard one [2] because it focuses on those measurable aspects of a flow (material, energy, signal) that evolve in time because of the verb action.

This definition forces the attention towards

- What: the spatial, energetic, temporal, chemical, physical, etc.. attributes of the object of the action,
- Where: the direction of the variation
- When: the duration of the action
- Who: the tool used to perform the action
- How: the way the attributes are forced to vary by the verb.

This approach draws the attention towards a finite set of measurable parameters.

Enlarging a functional data base it becomes difficult for the system to discriminate correctly between functional and non-functional verbs. In addition, we are interested in keeping within the enlarged database of verbs that, although clearly non functional, may be useful when structural or logical representations are needed. In order to pursue these goals, we introduce a novel classification (see Table 1). The developed application tool is able to highlight in the text these verbs by different colours.

Table 1. Classes of verbs

Structural verbs:	Structural verbs [14] are particular functional verbs that sometimes are used to describe the product structure. Since this double use [15] have to be disambiguated by the analyst. Since the patent often describes an artefact, in its description structural verbs predominate with respect to functional ones. Therefore the analyst, if interested in functional content, can easily filter all the other aspects.
Near-functional verbs:	This class of verbs does not belong to the functional one because they do not satisfy the definition of function given above and in [6]. However they can be fundamental because they often precede a function or are generally used with other additional words to describe a function. The most important one is the verb *to be*, often used in a functional meaning e.g. "component 14 is a resistor" or "components 13 is conductive". Other examples are *to work (as), to act (as)* etc.. where the function is expressed by the word(s) after *as, like,* etc.

Ambiguous verbs:	Ambiguous verbs are verbs with more than one meaning. After the analyst had disambiguated them, he has to check whether they are improperly used as synonyms of more specific verbs and to convert them in the nearest functional one.
Macro verbs:	Macro verbs are macro-boxes containing a series of single functional verbs. They have to be split in order to bring all the verbs at the same hierarchical level. After the engine can easily recognise and atomize these verbs. Examples are: hammerweld (=hammer+weld), idle (=rotate+minimize energy), but also pick (=grasp+move), etc..
Eliminable verbs:	They are one of the major sources of garbage in clustering because they are often used in patents, paper, technical documentation, but do not add any real quantitative information to the text. They are in general used to explain, present, introduce a topic, declare, claim. Therefore they have to be removed from a functional point of view, although they play a key role in a weighting system [15] [16].
Logical Verbs	Logical verbs are not properly functional verbs because of they are used to describe the order of the action, to describe the logical states of functioning of an artefact. Examples are: wait, retard, etc.

2.3 Organisation of the new functional database

Two concurrent methods to classify the new verbs in a hierarchical structure have been adopted.
The first one exploits the relations of synonymy and near-synonymy among verbs. Actually, by clustering the verbs based on the relation "to be synonym of" it is possible to establish a common father for each cluster.

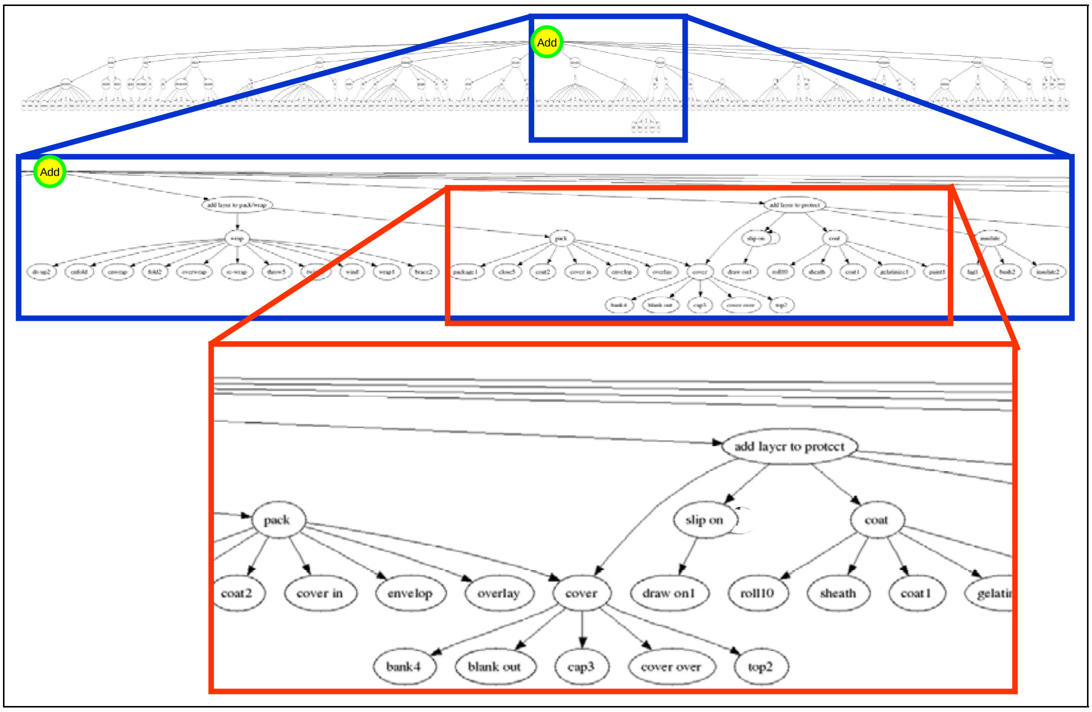


Figure 2. An extract of the global functional tree (the represented verbal root is "to add"). An example of a verb belonging to two different fathers is also shown.

The second one moves from the novel definition of functional verbs that, forcing the attention towards a finite set of measurable parameters, allows to cluster the data base according to one or more common parameters.
Cross-checking the two methods the entire verbal space has been organised in a hierarchical structure. Moreover, because of the existence of links among verbs belonging to the same level, the resulting

database is a complex net of verbs connected by both “father-child” relations and synonyms-antonyms ones. Figure 2 offers an extract of the functional tree, with synonyms and antonyms relations removed due to the constraints of a static visualization. Actually, the complete functional database is an enormous graph, nearly impossible to be visualised (but not to surf) because of the simultaneous existence of vertical and horizontal relationships.

3 CASE STUDY

The approach of describing functions by verbs, as described in the state of the art, started in the 1960s. However, it has not been completely accepted in engineering design practice, because it was perceived as a time consuming activity whose benefits were exceeded by the time resources requested.
Currently, a large verbal database can overcome many of these problems:

- the approach is simple and intuitive, because it starts from a technical description;
- the learning curve is rapid because it is not necessary to dominate and memorize all the functional tree and the definition of the root verbs;
- the final verbal hierarchy here proposed is close to the design language. Actually the assumptions used to construct the functional tree are less rigid than those used in the past. In fact many verbs do not belong to only one root verb, but conversely are located at the boundaries among different verbs.

The the expanded functional ontology proposed here is based on the functional tree structure proposed by Hirtz et al., but contains such a large number of verbs to make possible the semiautomatic extraction of functional information (but also structural and logical) from a technical text. Semiautomatic means the designer can rapidly check the cases of verbs with multiple meaning, disambiguate them accordingly with the context and then proceed to the analysis, block diagrams etc.. The cases study presented below are aimed at demonstrating the potentiality of the new approach.

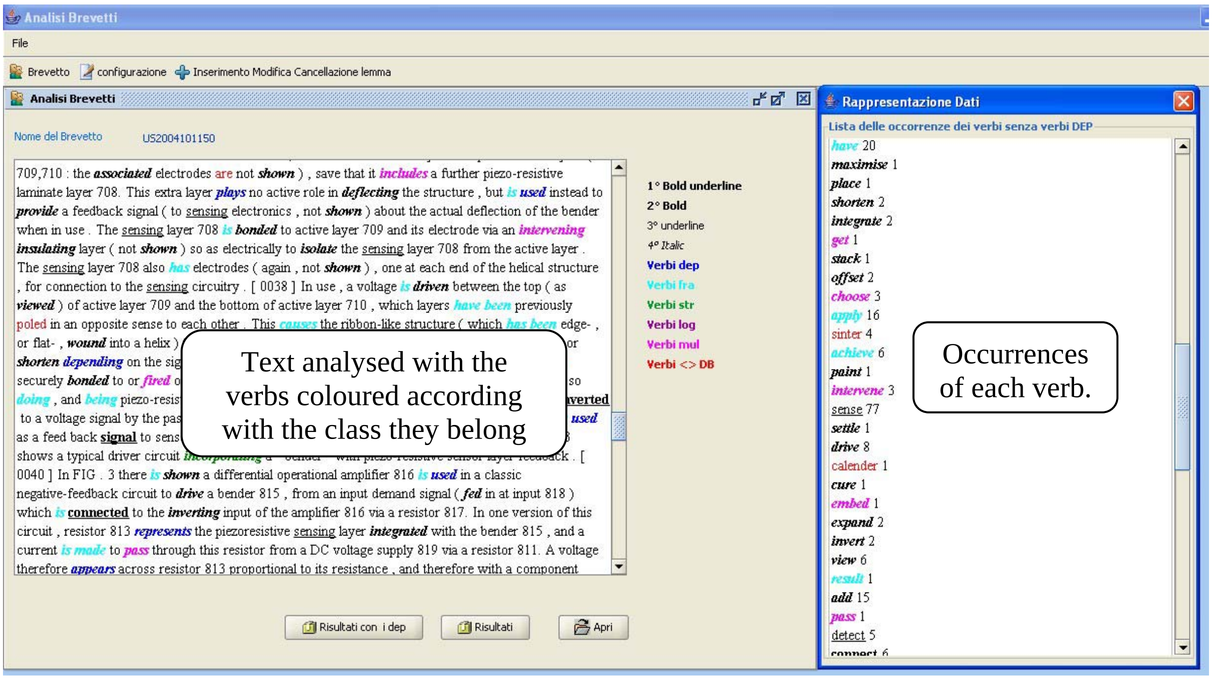
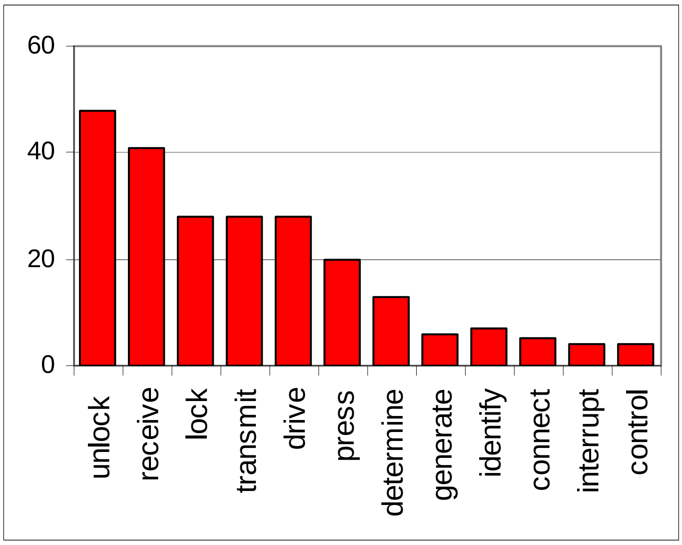


Figure 3. Screenshot of the software application tool

Moreover the verb classification introduced in section 2.2 can be used to selectively extract from the technical text functional, structural, logical information on the basis of the designer’s focus. As discussed by Bonaccorsi [18] the functional, logical and structural representations/maps are linked but often analysed separately. The idea is to allow the designer to switch from a representation to the next one or conversely to maintain the overall view of the product (with all the maps).
A long collaboration with automotive company Magna Closures persuaded the authors to test the final prototypical software application on a series of patents concerning car door and latches. Nowadays a very interesting challenge for automotive industry, and in particular for the supplier of car doors or car

latches, is represented by keyless door obtained by a passive entry system. Several patents are recently appearing and trying to claim many alternative solutions or, in other words, functional variants.
The system (a screenshot is shown in Figure 3) is based on the occurrence analysis, that not only counts the verbs but also determines their relevance according to the position in the patent (title, abstract, description of the preferred embodiment, independent claims, dependent claims [15]). Therefore a rank of the relevant functions performed by the invention is determined and shown in order to focus the attention to the patent original aspects.
The patent selected for this case study belongs to the IPC E05B and is related to a keyless entry system that locks and unlocks doors of a vehicle.



a

	Relevant Functional verb	Occ.
1	unlock	48
2	receive	41
3	lock	28
4	transmit	28
5	drive	28
6	press	20
7	determine	13
8	generate	6
9	identify	7
10	connect	5
11	interrupt	4
12	control	4
	Total	232

	#	occ.
Relevant Functional verb	12	232
Functional verbs	43	277
Non functional verbs	36	283
Total	**79**	**792**

b

Figure 4. a) Pareto's diagram of the most relevant verbs and b) summary of the results obtained by the analysis of patent US2006197379

An automatic summary of the patent (see Table 2) can be obtained by collecting those paragraphs having the higher score, that is with a number of relevant verbs higher than a threshold value (here assumed to be three). These paragraphs can then be ordered by computing their relevance as well. Their score is evaluated by a weighted sum of the three more relevant functional blocks (TFA) in the paragraph. This approach focuses on the key functional paragraphs where the description is strictly based on the core of the invention. It allows the reader to reduce time wasting far from the patent kernel.
By using the text miner it is possible to convert all the sentences in the active form and then to extract all the functional triplets formed by subject (Tool), verb (Function), object (Artefact). This TFA series of blocks are the elementary units to draw the block diagram (in scale 1:1). Usually the blocks are expressed by more general verbs, so that the hierarchical relation father child can be used. The result of this abstraction is a text where "blocks" are evidenced and can be rapidly transformed in a standard block diagram.
More than one step in the hierarchical structure can be performed (child-father-grandfather), but the resulting patent text often loses its readability. Therefore the generalisation obtained by one level of abstraction has been used for the patent US2006197379. In general two levels of abstraction can deeply damage the content. In this case, because the patent does not use very specific verbs, a double step in the hierarchical tree does not affect the comprehensibility of the reading.
Actually, in these cases the previous described procedure and the software application speed up the analyst's work in compiling/drawing the block diagram. The analyst has to decide the meaning of the ambiguous verbs and check whether the root/father verb proposed by the application is correct. An example of a block diagram obtained for patent US2006197379 is shown in Figure 5.

At present, the scanning operation can not be performed in a totally automatic way by the software, because even the most powerful parsing software tools are not able to discriminate the different meanings of a word. Therefore the operator has to solve these ambiguities. However, once he has assigned the right meaning to the ambiguous verb, the software is able to provide a text with all the verbs at the third (or upper) level. This feature reduces the time necessary for the analysis and opens the possibility in the near future to think about automatic conversions of this abstract text in a block diagram (in analogy with [15]).

Table 2. Automatic summary of patent US2006197379 (obtained considering all the verbal forms: verbs, adjectives belonging to a verb, etc..)

Paragraph
The present invention ***relates*** to a keyless entry system that ***locks*** and ***unlocks*** doors of a vehicle by signal transmission from a portable transmitter, and more particularly, to a keyless entry system that can properly ***perform*** ***locking*** and ***unlocking*** even when the portable transmitter is ***operated*** a plurality of times in a short time.
The keyless entry system shown in FIG. 4 ***includes*** a portable transmitter 50 in which a unique identification (ID) code is ***set*** and which is capable of wireless communication, and an operation unit 60 ***installed*** in the vehicle to ***lock*** and ***unlock*** the doors of the vehicle in response to a lock signal and an unlock signal ***received*** from the portable transmitter 50.
The lock switch 53a is ***pressed*** to **transmit** a lock signal, and the unlock switch 53b is ***pressed*** to **transmit** an unlock signal.
In the unlocking operation, only a door beside the driver's seat is ***unlocked*** when a first unlock command signal is ***received***, and the other doors are ***unlocked*** when a second unlock command signal is ***received*** within a predetermined time (e.g., five seconds) after the reception of the first unlock command signal.
The operation unit ***includes*** a receiver that ***receives*** the lock signal or the unlock signal **transmitted** from the portable transmitter, and that outputs a lock command signal or an unlock command signal ***having*** a predetermined time length, and a controller that ***drives*** actuators to ***lock*** or ***unlock*** the doors of the vehicle in response to the lock command signal or the unlock command signal output from the receiver.
Preferably, the controller ***drives*** the actuators to ***lock*** all the doors when the lock command signal is input from the receiver, ***drives*** only the actuator corresponding to a door beside a driver's seat to ***unlock*** the door beside the driver's seat when the unlock command signal is first input, and ***drives*** the actuators corresponding to the doors other than the door beside the driver's seat to ***unlock*** the doors other than the door beside the driver's seat when the unlock command signal is input again within a predetermined time.
The receiver 20 ***includes*** an antenna 23 for ***receiving*** a lock signal or an unlock signal from the portable transmitter 1, a ***receiving*** circuit 21 for ***modulating*** the signal ***received*** by the antenna 23, and a control circuit 22 for **processing** the signal ***modulated*** by the ***receiving*** circuit 21.
The first terminal 36 is **connected** to a motor 4a for ***locking*** or ***unlocking*** the driver's seat door, and the second terminal 37 is **connected** to three motors 4b for ***locking*** or ***unlocking*** doors other than the driver's seat door and to a motor 4b for ***locking*** or ***unlocking*** a trunk door.
The driver's seat door is ***unlocked*** by ***driving*** only the motor 4a when a first signal ***is received***, and all the doors other then the drive's seat door are ***unlocked*** by ***driving*** the four motors 4b when a second signal is ***received***, for example, within five seconds after the input of the first signal.
As shown in FIG. 2A, when the lock switch 12a is ***pressed*** twice at an interval of one second or more, the controller 30 ***receives*** the first lock command signal output from the receiver 20 before the receiver 20 ***identifies*** the second lock signal, and outputs a current for ***driving*** the actuator 4, thus ***locking*** all the doors.
As shown in FIG. 2A, when the unlock switch 12b is ***pressed*** twice at an interval of one second or more, the controller 30 ***receives*** the first unlock command signal output from the receiver 20 before the receiver 20 ***identifies*** the second unlock signal, and the two ***pressing*** operations of the unlock switch 12b do not ***interfere*** with each other.

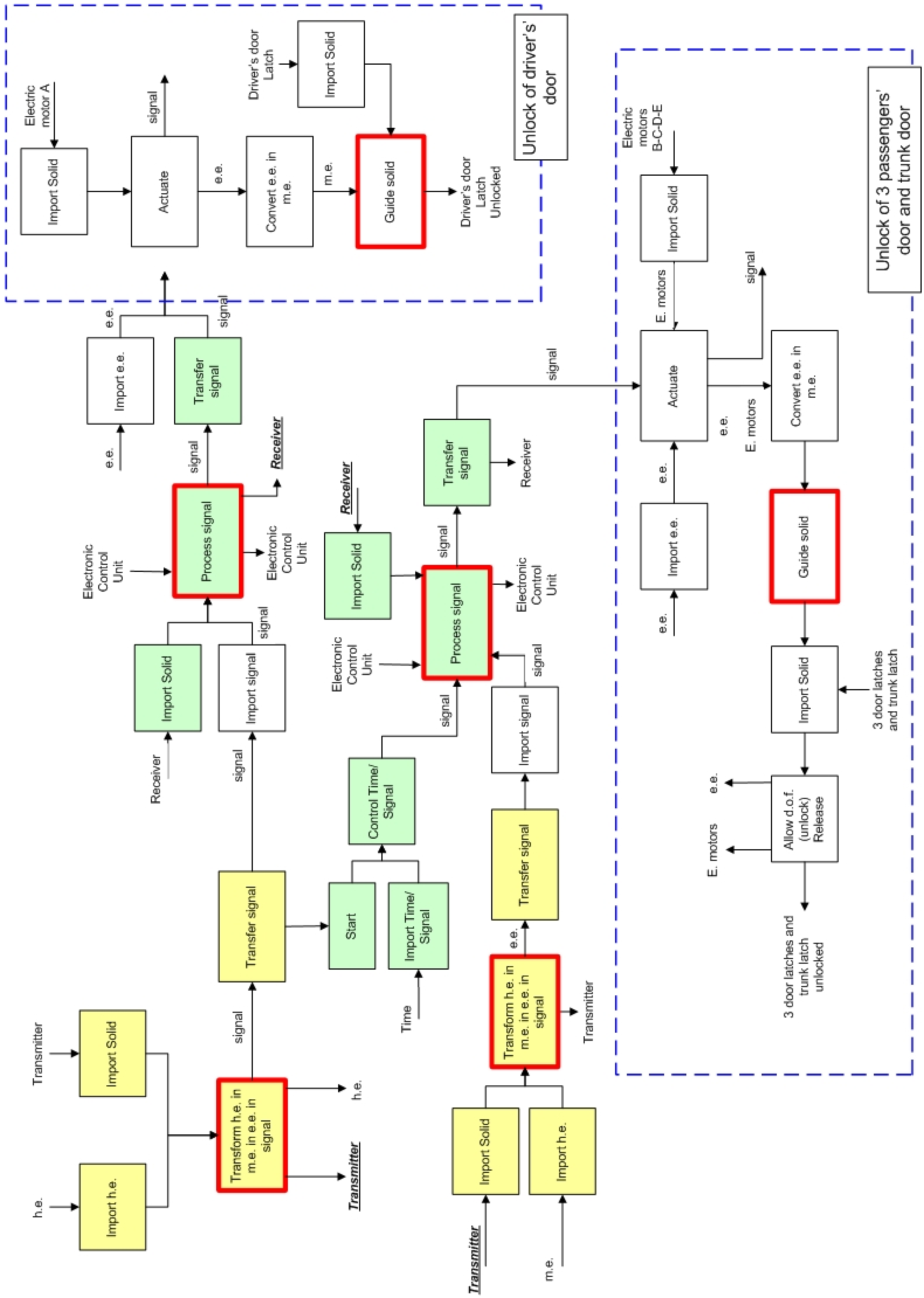


Figure 5. Simplified block diagram concerning the unlocking sequence in US2006197379: yellow blocks represent the functions in the transmitter, the green ones those in the receiver, actuation is contained in the dotted blocks, while red line blocks "contains" two or three smaller blocks.

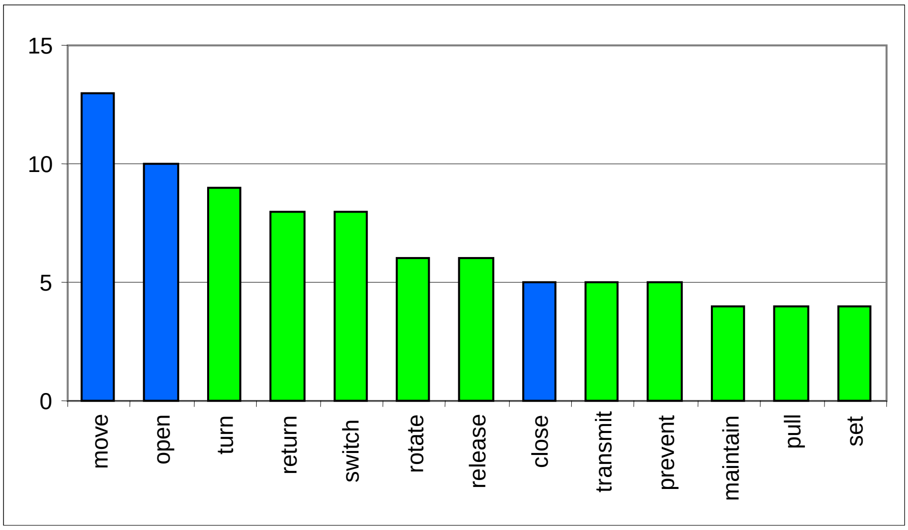


Figure 6. a) Pareto's diagram of the most relevant verbs obtained by the analysis of patent US2006191304

From the same IP class E05B different kinds of patents can be extracted. Figure 6 presents the results of verb analysis concerning "a door lock system applicable to vehicles" patented in US2006191304.
It immediately emerges that the invention relates to a mechanism: *to move*, *to open* and *to close* (with *to lock* and *to unlock* and their synonyms, represented in blue in Figure 6) are the main verbs for patents concerning car latches (e.g.; Pat. US2004160066, Pat. WO0020710). Here however *to turn*, *to return* and *to switch* focus the analyst attention towards the core of the invention: a rotating system that *locks* and *unlocks* the car latch by the simple *turning* and *returning* of a *switching* lever.
Clustering obtained by verb analysis allows also to observe anomalies, as for example in Pat. WO03033847 or Pat. US2003070457. Actually, as shown in Figure 7, when neglecting the structural verbs and the typical verbs for the class of latches, the verb *to connect* exceeds the others.
As revealed by the verbal cluster analysis, the two patents presented the same concept: splitting the car latches into two *connected* parts by separating the command logic (positioned in the centre of the door) from the strength module (that remains in its standard position), but emphasise/claims different aspects.

US2003070457		
#	verb	%
1	connect	8%
2	**unlock**	**4%**
3	*locate*	*4%*
4	**lock**	**4%**
5	combine	3%
6	trigger	3%
7	pull	3%
8	fix	3%
9	*arrange*	*2%*
10	integrate	2%
11	couple	2%

Pat. WO03033847		
#	verb	%
1	*comprise*	*8%*
2	connect	8%
3	actuating	5%
4	*support*	*4%*
5	*project*	*3%*
6	**open**	**3%**
7	secure	3%
8	*extend*	*3%*
9	pivot	2%
10	**release**	**2%**
11	**lock**	**2%**

Figure 7. a) Comparison between the most relevant verbs obtained by the analysis of patent WO03033847 and patent US2003070457

Even if the event is quite rare, sometimes the occurrences of verbs in claims and description differ. One of this cases is represented by Patent GB1282726 where the description contains prevalently structural information about how the device (the main verb is *to support*) obtains a specific aim, while the claims focus on the goal the authors want to achieve (*to orient*).

These infrequent cases have to be monitored with particular attention because they could hide interesting information as for example differences between the wanted aims and the physical device. In fact the same question "Why should the description provide different information from claims?" does not bring to a complete answer, unless we think a planned intention of diverting the technician's attention from the considered patent.

4 CONCLUSIONS AND FUTURE DEVELOPMENTS

As shown thorough the analysis of the two different patents belonging to the same IP class, the developed system is able to help the analyst in functional analysis, clustering and modelling (by block diagram). Moreover the text analysis based on verbs could show some interesting results as for example by highlighting very innovative patents which use "unusual" verbs repeatedly.

Therefore the tool, which demonstrated powerful characteristics in the analytical phase, may be used as a support to creative problem solving in very early stages of product development. In particular, any new idea expressed in natural language by designers may be readily associated to a few functions by the analyst. After that, the tool will produce a structured map of clusters of functions, depending on horizontal and vertical relations, upon which a thorough analysis of the constraints may be done. Working on synonyms and antonyms within a given functional block helps to generate more new ideas and of better quality. New searches can be done iteratively, leading to a much improved ability to identify good ideas in conceptual design.

The authors are actively developing all these directions. There are however some issues to solve. First, the initial set of analyses has been performed by using an open source text miner (TreeTagger [23]), which was suitable for expanding the functional ontology, but not so advanced to allows a fast and reliable recognition of the semantic value of a word in a sentence. Therefore the analysis requested some time spent in controlling the software output. We are planning the use of more powerful commercial software. Secondly, the graphical features of the tool might be improved. Finally, while the tool has been "trained" on the basis of patents, verb extraction from technical papers and technical dictionaries is planned in order to enrich it further.

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