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Method and device for assessing germination traits of plant seeds

Description

5 The present invention concerns a method for automating the objective assessment of germination traits of plant seeds and seedlings developing from the plant seeds in which the plant seeds and seedlings are situated in a dense medium serving as a germination base, particularly filter paper or soil, based on anatomical characteristics at a certain point in time.

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Inventive step

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Although the following primarily refers to sugar beet seeds, the invention is not limited but in principle is applicable for all agriculturally or scientifically relevant plants.

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A seed must have certain minimum quality characteristics to guarantee sufficient emergence and growth in the field and also to satisfy legal requirements of the International Seed Testing Association. The quality of the seed is a decisive factor that can develop the respective genotypic harvest and quality characteristics.

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The goals of the seed research include ensuring as much as possible an early, high and consistent emergence, a high emergence rate, a good growth performance and a high stress tolerance. Therefore, this should achieve the greatest possible consistency of growth, i.e. the developing plants and plants that are ready to be harvested, as well as a high and consistent harvest in terms of quantity and quality.

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In the propagation cultivation which serves to produce seeds, the influence of cultivation techniques on the seed characteristics is evaluated and controlled.

Based on this, new, agreed production methods are being developed to improve and stabilise the yield and quality of the raw materials of the seeds.

One quality characteristic of seeds is their earliest possible germination. It is generally determined according to the standards of the International Seed Testing Association (ISTA).

The seeds are thus germinated in dampened filter paper of defined quality under controlled humidity and temperature conditions over a determined period of time. After this period of time, the germinated seeds are counted manually.

It is known that specified morphological, anatomical and physiological seed
5 characteristics have significant influence on the germination and emergence performance in the field.

To obtain more information about the quality of sugar beet seeds, for example, a series of different testing procedures are known through which, for example, the
10 emergence potential may be predicted under field conditions. A summary is available by H. P. Draycott (ed.): "Sugar beet", World Agriculture Series, Blackwell Publishing, 2006.

MAISL Michael, KASPERL Stefan, WOLFF Antje: "Process Monitoring using Three
15 Dimensional Computed Tomography and Automatic Image Processing", ECNDT 2006 Proceedings, 27 September 2006, presents a method for computed tomographic 3-dimensional illustration of sugar beet seeds. The inspection of the seeds takes place first after the seeds are received, another time after the seeds are polished and a third time after the seeds are sieved. Germinating seeds or
20 seedlings are not inspected. Nor does an inspection take place during the course of germination. The seeds are isolated in a specimen holder in respective recesses in this sheet, whereby the specimen holders are stacked together. The specimen holders then serve simply to hold and stack the individual seeds. Consequently, there is no inspection of germinating plant seeds and seedlings in a dense medium
25 serving as a germination base.

Known methods for determining the germination characteristics often have a disadvantage in that the assessment does not take or barely takes the objective deciding factors as a basis. Furthermore, conventional methods can only obtain a
30 small scope of information which allows a prospective assessment of a seed, that is to say, a prediction of its germination and particularly the germinating power in the field. A seed with high germination capability does not necessarily also have a high germinating power. So the germination capability alone does not have any influence on the stress tolerance, for example, of the developing plants.

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Conventional methods are also often labour-intensive and require high numbers of personnel. Because it essentially concerns manual tests, agreed parameters from the individual assessment are dependent on the test personnel and thus difficult to standardise. Another constraint regarding the ability to standardise results from test media not always being consistently available, such as comparing inspections of necessary (standard) soils.

The respective tests furthermore normally take place under agreed, defined laboratory conditions where in each case only one agreed parameter (humidity, ground cover etc.) is inspected. Therefore, it is difficult to draw conclusions on the field behaviour.

There is a need for automatic, particularly fully-automatic, objective testing methods for assessing the germination capability and germination quality of seeds.

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Disclosure of the invention

Against this background, the present invention proposes a method with the characteristics of claim 1. Advantageous embodiments are indicated in the dependent claims and the following description.

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Advantages of the invention

The present invention allows the development from seeds to plants above and below the ground, taking into account leaves and roots (beets) in order to make documentations in a non-destructive way. For this purpose, seeds are initially inspected in a dense medium by the image-producing computed tomography method and then moved for further cultivating in a germination area. In a chronologically staggered order, inspections are once more performed during the course of germination. Through the largely automated execution of the method, any inspection intervals can be implemented which are no longer dependent on the availability of personnel.

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According to the invention, the inspections take place while the seeds are located in a germination base. The pleated filters which are conventionally used in the

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germination tests can be used as germination bases, however, it is also suitable to be used for the presented method as well as for inspecting germination in other mediums, e.g. in soil.

5 By means of the presented method, plant seeds and seedlings germinating from them are inspected using as least one of the image-producing computed tomographic methods and by preserving inspection data from a certain point in time in a chronologically staggered order during the course of germination.

10 The inspection data obtained from a certain point in time is then submitted in the form of 3D image data for each image processing method or algorithm. Within the course of this image processing method, each of the depicted seeds and developing germinating plants are first segmented from the germination base, for example from a pleated filter or from soil.

15 The term "segmentation" is to be understood in the course of this application as a distribution of image ranges or areas of inspection data to the area of an inspected object, which particularly takes place using the procedure of the computerised image processing technology.

20 Besides the segmentation of depicted seeds or germinated plants on one side and the germination base on the other side, a segmentation and distribution of the image segments to anatomical units of the plant seeds or seedlings furthermore takes place.

25 The characteristics of these anatomical units based on the particular investigation time are derived from the correspondingly allocated anatomical units or the image areas corresponding to them. The derivation of the features may favourably take place by using an algorithm by means of which image areas can be surveyed
30 three-dimensionally.

The assessment of the germination properties of the plant seeds takes place on the basis of the anatomical characteristics thus obtained that are related to a particular point in time.

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The term "germination properties" is thereby to be understood as, in addition to the minimum germination capacity as well as particular emergence, the speed of emergence, the growth performance, the stress tolerance, the uniformity of growth, the seedling quality such as the lengths and/or volumes of shoots and roots, the speed of development and substance properties thereof and possibly other properties derived from these. A germination property can thus also be a property of a seedling that has emerged from the plant seed as a result of germination (for example, the size of the cotyledons and size, length and substance properties of the roots) and particularly the development of this property over time. Furthermore, this also includes properties of seeds which can be attributed to it as a result of the method according to the invention (i.e. predicted properties such as the probable minimum germination capacity or speed of emergence). The colour of the tissue (black colouration) makes it possible to comment on the possibility of a fungus attack on the seedlings at the end of the germination period.

Computed tomographic imaging methods are used within the scope of this method. The computer tomography and magnetic resonance tomography enable a non-destructive, three-dimensional measurement of the germinated plants or seeds in a germination base which does not need to be removed in order to inspect the material. This results in allowing a completely non-disruptive and non-destructive manner of measuring the plants without having any effect on germination.

A particular advantage is seeds or seedlings being introduced into the beam path of an x-ray or magnetic resonance tomograph, being rotated in the beam path and subjected to spatially resolved imaging tomography.

Furthermore, in addition to the tomographic methods presented, an optical inspection may also be advantageous. For example, at the end of the germination period or a corresponding inspection time, an assessment may be made by using one or more imaging sensor, for example, a colour camera, whereby the hypocotyl colour, for example, and any possible colour change that may have occurred due to a fungal infection can be detected, or by using a magnetic resonance method.

A particular advantage is the plant seeds or seedlings developing from them under controlled conditions are incubated in a germination device, for example a phyto-chamber. Before the inspection, the seeds or seedlings are introduced, for
5 example, into the magnetic resonance tomograph, preferably fully automatically, and then returned to the germination device.

As mentioned before, a particular benefit is that by using the computer or magnetic resonance tomography methods, the plant seeds and/or seedlings can
10 be investigated in a freely selectable germination base that only must be adapted to the particular method of inspection. For example, the germination base may consist of the pleated filters mentioned above, soil or any other suitable medium. Because of this possibility, different growth conditions, for example different soil qualities, can be simulated.

15 A particular advantage is that this method comprises examining plant seeds in the dry state, moistened plant seeds and/or seedlings at different times.
First, for example, tissue parts of dry seeds may be analysed by inspection, segmentation and derivation of the anatomical characteristics relating to a certain
20 point in time. For this purpose, the seeds are positioned, for example, between the pleats of a vertically positioned pleated filter and the filter with the seeds is introduced, first in a dry state, into the beam path of the x-ray or magnetic resonance tomograph.

25 The pleated filter is then moistened as defined and exposed to controlled germination conditions. At certain intervals of time during germination, (automatic) tomography with subsequent image assessment, as explained previously, is carried out which results, in addition to the three-dimensional data obtained, in a fourth dimension, namely the development of tissue parts over
30 time.

It is considered particularly advantageous to use the method described above to detect, as anatomical units of the plant seeds, the hard pericarp, the soft pericarp, the embryo and/or the endosperm tissue, because these anatomical structures
35 provide particularly significant data for assessing the germination properties.

According to the invention, the radicle, the hypocotyl and/or the cotyledons of the seedlings are studied.

5 The various anatomical characteristics relating to a certain point in time comprise a volume, an area, a dimension (length, width) and/or, if it can be detected by the imaging method, colouration of the anatomical units. The volume of the endosperm tissue makes it possible to draw conclusions, for example, regarding the supply of the nutrients to the embryo and thus the germination quality. The volume or area of the cotyledons allows conclusions to be drawn, for example, 10 regarding the assimilation capacity of the developing seedlings. The length and strength of the hypocotyl make it possible to comment on its stretching potential. The faster the cotyledons can penetrate through, for example, muddy soil and can start to assimilate sunlight, the earlier and more effectively the formation of the substance and thus the yield can begin. The growth rate, the length and branching 15 of the roots allows conclusions to be drawn regarding the water supply and the anchoring of the seedlings in the soil.

As already explained, a particular advantage is that the presented method makes it possible to evaluate the germination capacity and/or the germination quality of 20 the plant seeds, even in advance. The method according to the invention therefore provides a particularly simple and advantageous way of establishing an automatic germination test which is suitable for replacing, objectivising and automating conventional test methods.

25 As is also already explained, the assessment of the germination properties comprise an appreciation of the anatomical characteristics relating to a particular point in time over a predetermined period, which corresponds, for example, with time segments of a germination period that are considered to be significant.

30 A particular advantage is that the assessment of the germination properties comprises the comparison of the anatomical characteristics relating to a particular point in time with comparative and/or threshold values. A particularly simple manner of correlating characteristics that have been observed with comparative values and of commenting on the order of magnitude of the developing seedlings

or their properties is possible. The comparison with threshold values can also be used in particular for assessing seed batches.

To be able to derive more accurate information on the germination properties, it can be advantageous to carry out a statistical assessment of the anatomical characteristics relating to a particular point in time. For example, by taking the average of many measurements of different individuals (large random sample), it is possible to eliminate the biological (intravarietal) variations within a species or treatment.

The method can also include correlating a germination development with properties of anatomical characteristics of dry seeds. For example, it is possible to statistically classify the types of development, over a period of time, of all or some of the characteristics and then assign them to relevant seed characteristics. In this way, it is possible to reach a prognosis based on the seed characteristics as to the germination properties that can be expected and, for example, to grade seeds into superior or inferior grades within the scope of the production of quality seeds.

One advantage is that the process according to the invention makes it possible to evaluate the germination properties while simulating stress factors (drought, unfavourable soil type). For this purpose, for example, the water content of the filter paper which serves as a germination base may be changed, there may be a change in the depth of the seed placement in the filter and/or the filter pleats of a vertically positioned filter may be more or less compacted above and below the seed. Based on the automatic image assessment, the qualitative statements derived from it and the absolute ability to standardise which is achieved in this way, the method is also suitable for the objective assessment of germination capacity and growing power in official seed testing.

A device for evaluating germination properties of plant seeds is also the subject of this application. Regarding the characteristics and advantages of this device, reference is specifically made to the characteristics of the method according to the invention which were described previously.

In particular, a device of this type comprises a means for segmenting and/or means for deriving anatomical characteristics relating to a particular point in time which are embodied as software means, particularly in the form of computer-implemented algorithms.

5

Further advantages and features of the invention will become apparent from the description and the accompanying drawings.

10

It shall be understood that the characteristics mentioned previously to and those which will be described hereinafter may be used not only in the particular combination described, but also in other combinations or on their own without departing from the scope of the present invention.

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The invention is schematically illustrated in the drawings by means of embodiment examples and is described in detail hereinafter with reference to the drawings.

Description of the drawings

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Figure 1 shows a pleated filter with seedlings in a germination test according to the prior art.

Figure 2 schematically shows an arrangement for carrying out the method according to a particularly preferred embodiment of the invention.

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Figure 3 shows photographs of sugar beet seeds using imaging techniques.

Figure 4 shows a partial sectional view of a 3D reconstruction of sugar beet seeds from computed tomographic images.

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Figure 5 shows computed tomographic images of sugar beet seeds and segmented illustrations obtained by methods according to a particularly preferred embodiment of the invention.

Figure 6 shows volume data of segmented tissues from sugar beet seeds obtained by a method according to a particularly preferred embodiment of the invention.

5 Figure 7 shows computed tomographic images of sugar beet seeds according to a particularly preferred embodiment of the invention and corresponding seedlings.

10 Figure 8 shows a correlation of a seed quality index obtained according to a particularly preferred embodiment of the invention with a field emergence property in the case of the sugar beet.

15 Figure 9 shows a germination test in a vertical pleated filter according to a particularly preferred embodiment of the invention.

Figure 10 shows computed tomographic images of ungerminated sugar beet seeds according to a particularly preferred embodiment of the invention.

20 Figure 11 shows 3D reconstructions of germinated sugar beet seeds according to a particularly preferred embodiment of the invention.

Figure 12 shows 3D reconstructions of germinated wheat seeds according to a particularly preferred embodiment of the invention.

25 Figure 13 shows 3D reconstructions of germinated maize seeds according to a particularly preferred embodiment of the invention.

Figure 14 shows a schematic illustration of an arrangement for carrying out the method according to a particularly preferred embodiment of the invention.

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In the figures that follow, identical or analogous elements such as seed or seedling characteristics, for example, have been given the same reference numerals and are not described again, in the interest of clarity.

In Figure 1, a pleated filter with seedlings is shown as used in a germination test according to the prior art. The arrangement as a whole is designated 100. As explained previously, in conventional germination tests seed 102 is introduced into a horizontally positioned pleated filter 101 and after the addition of liquid, the seed is germinated under widely defined conditions. The seedlings 103 developing from this are then assessed, for example counted.

Figure 2 schematically shows an arrangement for carrying out the method according to a particularly preferred embodiment of the invention and is as a whole designated as 200. The arrangement 200 comprises an x-ray device 210, for example a computer tomograph 210 with an x-ray tube 211 and an x-ray detector 213. A sample that is to be inspected, for example a filter with seeds in a holding device or seedlings in the germination base, is placed in the beam path 212 of the x-ray device 210. The sample is rotated in the x-ray device 210 in order to take sectional images, as illustrated by a rotary arrow ϕ , and pushed stepwise in the z direction.

The sectional images obtained are processed, for example, by means of a measuring computer. The measured data delivered by the measuring computer 230 via a high-speed network 250 are reconstructed by means of a high-speed computing device 240, for example a cluster of individual computers 241, and supplied to an evaluating or visualising computer 260.

In Figure 3, images of sugar beet seeds are obtained by means of imaging techniques. Image 310 shows a conventional digital photograph of a sugar beet seed or seed ball. Image 321 is a computed tomographic cross-sectional view of the sugar beet seed, whereby the direction of the section plane corresponds substantially to that of the plane of image 310. The computed tomographic longitudinal view which is taken perpendicularly to it is shown in image 322.

Figure 4 shows a partial sectional view of a 3D reconstruction 400 of a sugar beet seed from computed tomographic images such as those in Figure 3. In illustration 400, the seed husk 401, the cotyledon 402, the endosperm tissue 403 and a cavity 404 in the seed can be optically differentiated.

As explained previously, the method according to the invention comprises allocating the seedling characteristics to anatomical units by automatically segmenting. The automatic segmenting is illustrated in Figure 5. On the left-hand side of Figure 5, there are two computed tomographic sectional images 510, 520 of a sugar beet seed in the form of low-resolution photographs. On the right-hand side of the figure, there are segmented illustrations 515, 525 which are produced automatically by means of software. The segmented illustrations 515 and 525 show three or four segments or image areas 516-519 which may correspond, for example, to different anatomical units such as characteristics 401 to 404 in Figure 4. The detection of segments 516-519 from the sectional photographs 510 is carried out partially by using grey-scale values but also in particular by the correlation of the individual image data with serial photographs of sectional images and including correlations determined empirically from series of measurements.

In the seed shown in images 510 and 515, for example, a cavity 519 can be seen and has been allocated accordingly by segmenting, said cavity not being present in the seed shown in images 520 and 525. The presence of a cavity inside a seed and its sized can be used, for example, as a quality characteristic to evaluate seed properties.

Figure 6 shows data by way of example obtained from 50 successive computed tomographic photographs of sugar beet seeds. The respective coordinates of the computed tomographic measurement (X- and Y-position and shift in the Z direction) are shown in columns X, Y and Z. The table also gives a total seed volume V in mm³ as well as a volume of a first segmented characteristic x and a second segmented characteristic y in mm³.

In Figure 7, a correlation between measurable seed properties and a plant quality resulting from them is shown. 710 in Figure 7 shows three computed tomographic images 711, 712 and 713 of three seeds which have been subjected to a segmenting and allocation process according to the invention.

Within the scope of the example shown in Figure 7, a total seed volume and a cavity inside a seed (for example, corresponding to the cavity 404 in Figure 4 or

the cavity 519 in Figure 5) have been automatically detected. The values for the individual seeds 711, 712 and 713 are given (in mm³) in the following table:

Characteristic	711	712	713
Seed volume	2.80	3.52	4.19
Cavity	0.51	1.42	0.19

In line 720 of Figure 7, seedlings 721, 722 and 723 which correspond to the seeds are shown. It is clearly apparent that seedlings 721 and 722 show a significantly worse growth performance compared to seedling 723 corresponding to seed 713. The different plant qualities are attributed to different early emergence times in the field and also to different starting sizes of the embryonic tissue. It has been established that, in particular, the size of a cavity inside a seed is clearly correlated with the plant quality obtained. In the case of seed 713 in which this cavity is minimal, for example compared with seed 712 a particularly early emergence in the field and thus particularly good quality of the seedling 723 can be correlated.

By means of the seed or seedling characteristics determined according to the invention, including for example a cavity inside a seed, it is possible to draw up a seed quality index determined from a number of parameters. This seed quality index makes it possible, for example, to make predictions as to the field emergence characteristics of corresponding seeds.

This situation is illustrated in Figure 8. Figure 8 shows a diagram 800 in which a correspondingly determined seed quality index of seed parts of different varieties is plotted on the x-axis 810 against the proportion of early germinated (desired) plants on the y-axis 820 as a percentage. The graph 800 shows a correlation between the quality of the seed described by a quality index and the early field emergence. The data represent averages of three locations in which seeds from a provenance or genetic type A, genetic type B and a genetic type C were investigated. Within the individual genetic types a clear correlation can be detected between the seed quality index and early field emergence.

The person skilled in the art is aware that the field emergence characteristics of sugar beet seeds correlate to the sugar beet sizes that are subsequently achieved. A seedling or a seed with early or rapid field emergence, as explained above, has particularly fast access to water and/or nutrient salts and, because it has a
5 sufficiently well-developed leaf surface at an early age, it is able to fully and efficiently use its assimilation capabilities.

Figure 9 shows a germination test proposed according to the invention in a vertical pleated filter, as described previously. The arrangement as a whole is
10 designated 900.

A seed is introduced into a vertical pleated filter 910 and germinated in a moisture reservoir 920 in a vertical position. By compressing the pleated filter and/or varying the supply of moisture, different stress conditions can be simulated.
15 During the germination of the seed there is repeated computed tomographic inspections in order to obtain inspection data at a particular time which can then be subjected to an assessment method as described above.

Figure 10 shows a computed tomographic sectional image of a pleated filter 910
20 with dry seed 930 placed therein, obtained in this context. As explained previously, within the scope of this seedling text, images are taken layer by layer so that reconstructed three-dimensional data can be obtained.

Figures 11, 12 and 13 show corresponding 3D reconstructions which can be used
25 for non-disruptive and non-destructive assessment of the germination properties.

The partial figures A in Figures 11, 12 and 13 denote photographs which were taken three days after the germination began, partial figures B are photographs taken after six days and partial figures C show 7-day-old seedlings. Figure 11
30 shows maize, Figure 12 shows sugar beet and Figure 13 shows wheat seedlings. As was already established, the proposed method is thus suitable for investigating a wide range of varieties and types of plants that are of agricultural and scientific relevance.

Figure 14 shows a schematic structure of a device for germinating and tomographically inspecting seeds and seedlings germinating from them in a dense medium, for example in filter paper as illustrated in Figures 9 to 13. The device may be used in particular for the automated assessment of seedlings.

5

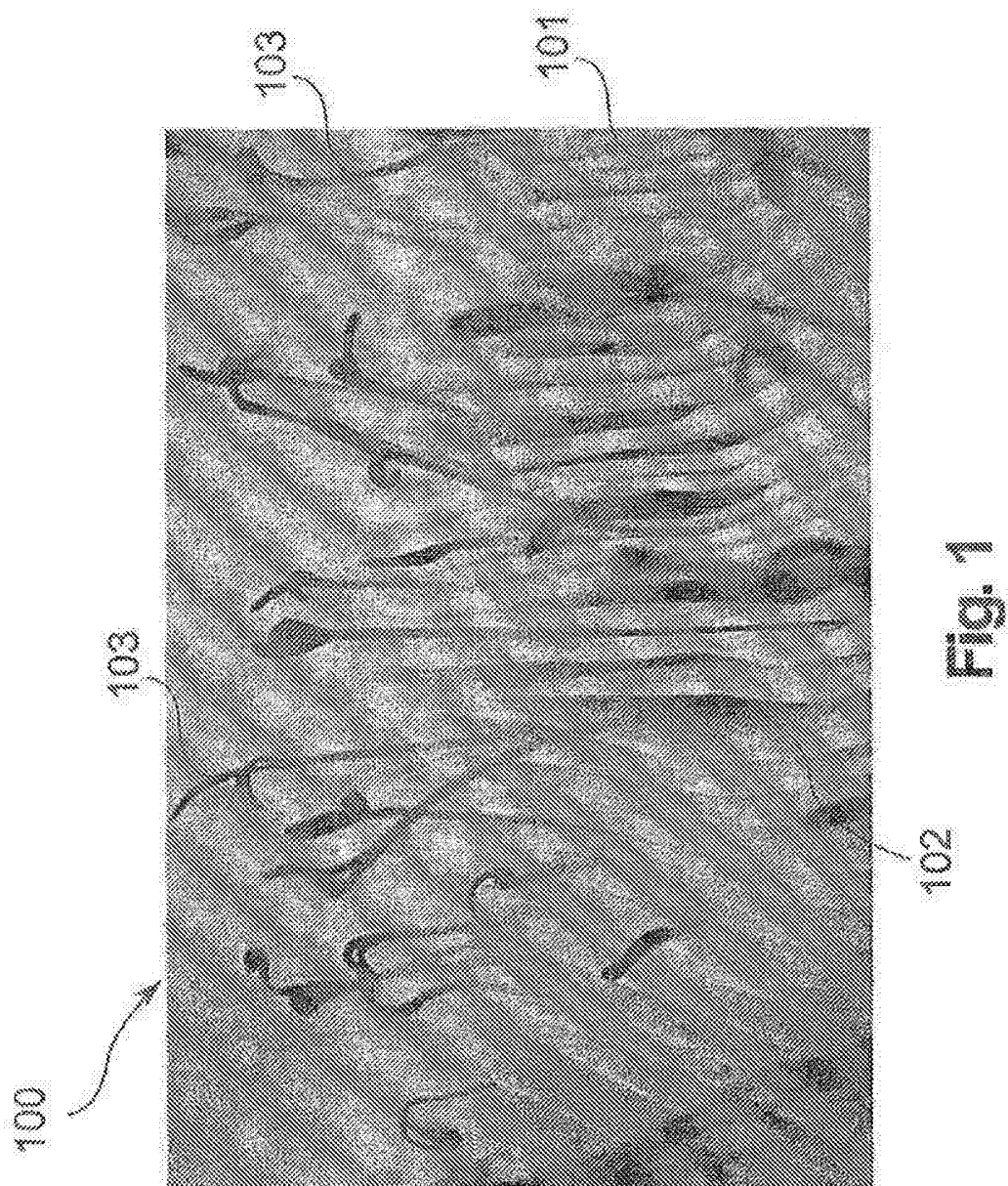
Reference numeral 1 denotes germination containers with seeds germinated in filter paper, soil or the like. The germination containers 1 are placed, by means of a transporting and displacement mechanism 2, in a tomography system 3 for non-destructive 3D inspection of the enclosed media and are subjected to spatially resolved tomography therein. After the inspection, the germination containers 1 are again conveyed through the transporting and displacement mechanism 2, for example placed in the germination chamber again.

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Patentkrav

- 1.** Fremgangsmåde til automatiseret, objektiv bedømmelse af spiringsegenskaber af plantefrø og af kimplanter som udvikles fra plantefrøene, hvor plantefrøene og kimplanter befinder sig i et tæt medie som et spiringssubstrat, i særdeleshed
- 5 filterpapir (910) eller jord, på baggrund af tidspunktsrelaterede anatomiske træk (x, y), hvor de tidspunktsrelaterede anatomiske træk (x, y) bestemmes i en forskudt tidssekvens under forløbet af spiring ved udførelse af trinnene a) til c):
- a) at undersøge plantefrøene og kimplanterne under anvendelse af mindst en billeddannelses-computertomografisk fremgangsmåde og at opnå
- 10 tredimensionel tidspunktsrelateret undersøgelsesdata (400),
- b) at segmentere den tredimensionelle tidspunktsrelaterede undersøgelsesdata (400), hvor de afbildede plantefrø og/eller kimplanter segmenteres fra spiringssubstratet, og at allokere opnåede segmenter (516-519) til anatomiske enheder af plantefrøene og/eller kimplanterne, og
- 15 c) at bestemme de tidspunktsrelaterede anatomiske træk (x, y) i form af en volumen, en flade og/eller en dimension af de anatomiske enheder af plantefrøene og kimplanterne fra de allokerede segmenter (516-519), hvor de anatomiske træk af mindst en af de anatomiske enheder kimrod, kimstængel og kimblade af kimplanterne bestemmes.
- 20
- 2.** Fremgangsmåde ifølge krav 1, hvor plantefrø i den tørre tilstand, fugtede plantefrø og kimplanter undersøges på forskellige undersøgelsestidspunkter.
- 3.** Fremgangsmåde ifølge krav 1 eller 2, hvor de tidspunktsrelaterede anatomiske
- 25 træk af mindst den hårde frøgemme, den bløde frøgemme, spiren og/eller frøhviden af plantefrøene bestemmes.
- 4.** Fremgangsmåde ifølge et hvilket som helst af de foregående krav, hvor en spiringskapacitet og/eller spiringskvalitet af plantefrøene evalueres som
- 30 spiringsegenskaber.

- 5.** Fremgangsmåde ifølge et hvilket som helst af de foregående krav, hvor bedømmelsen af spiringsegenskaberne inkluderer at detektere de tidspunksrelaterede anatomiske træk over en forudbestemt tidsperiode.
- 5 **6.** Fremgangsmåde ifølge et hvilket som helst af de foregående krav, hvor bedømmelsen af spiringsegenskaberne inkluderer at sammenligne de tidspunksrelaterede anatomiske træk med komparative og/eller tærskelværdier og/eller statistisk at analysere de tidspunksrelaterede anatomiske træk.
- 10 **7.** Fremgangsmåde ifølge et hvilket som helst af de foregående krav, hvor bedømmelsen af spiringsegenskaberne inkluderer korreleringen af tidspunksrelaterede anatomiske træk af kimplanter med tidspunksrelaterede anatomiske træk af plantefrø.
- 15 **8.** Fremgangsmåde ifølge et hvilket som helst af de foregående krav, hvor bedømmelsen af spiringsegenskaberne finder sted under simulering af stressfaktorer.
- 9.** Fremgangsmåde ifølge et hvilket som helst af de foregående krav, hvor
- 20 plantefrøene eller kimplanter i en lukket spiringsbeholder tages fra en spiringsindretning før undersøgelse og/eller returneres til en spiringsindretning efterfølgende.



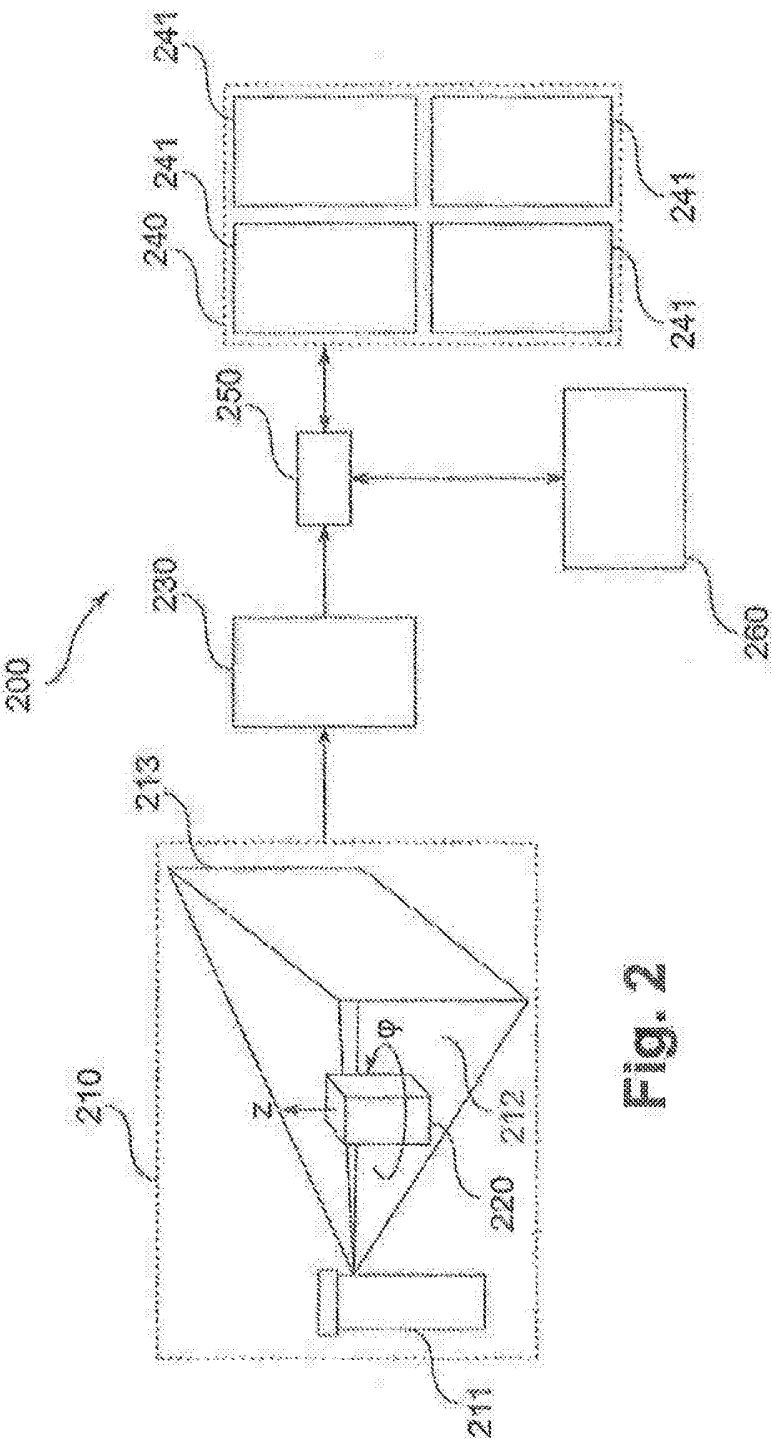


Fig. 2

EP 2 525 641 B1

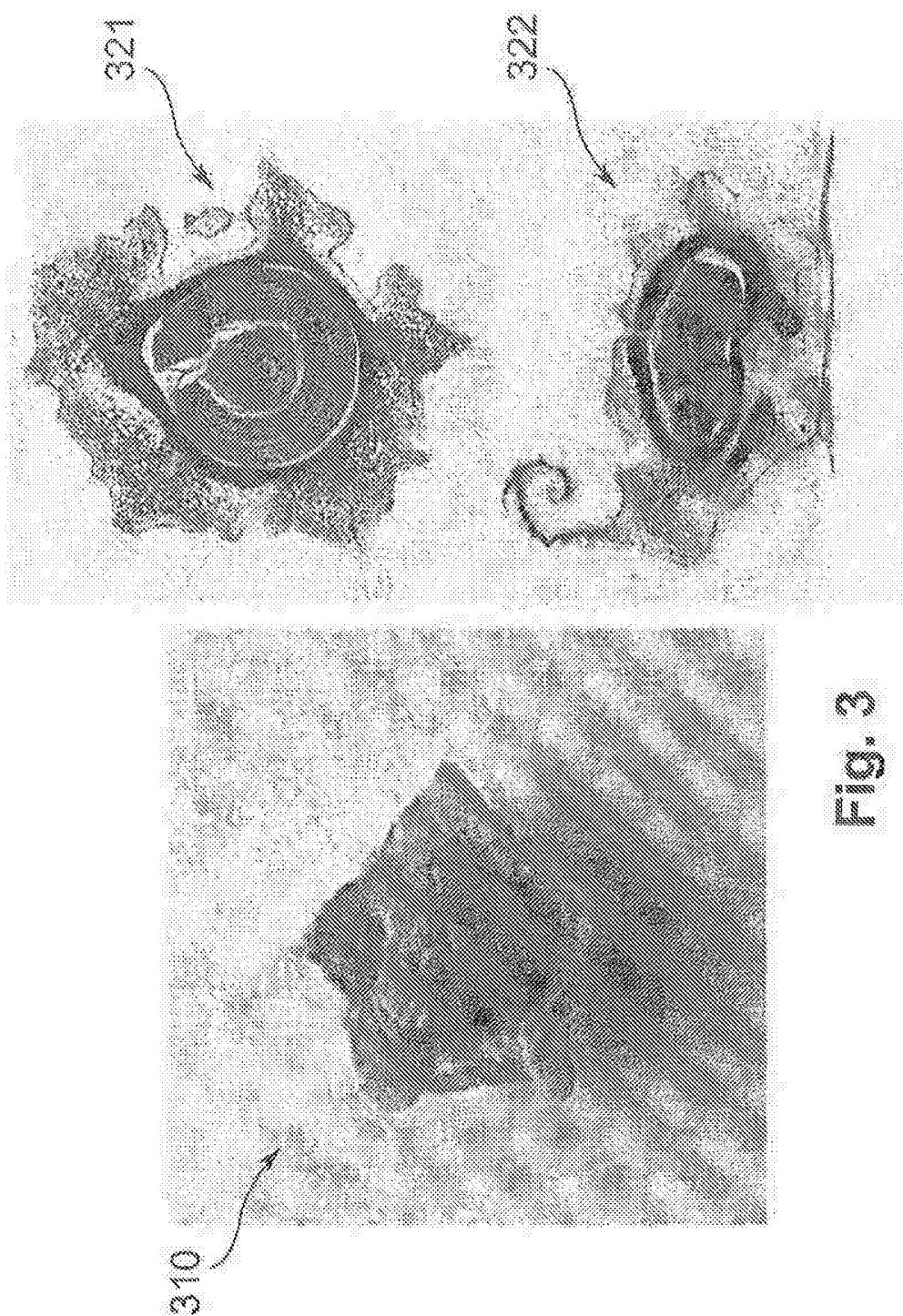


Fig. 3

EP 2 525 641 B1

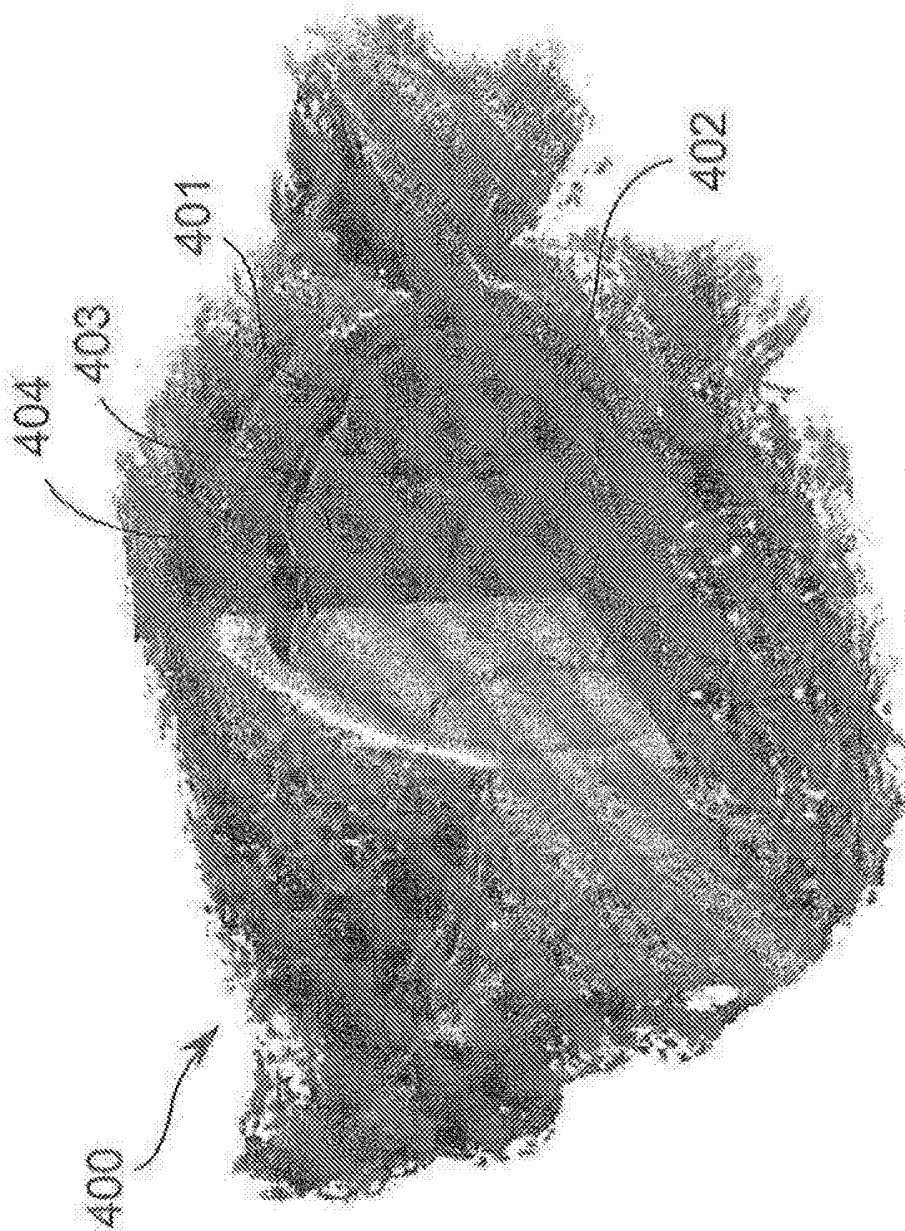


Fig. 4

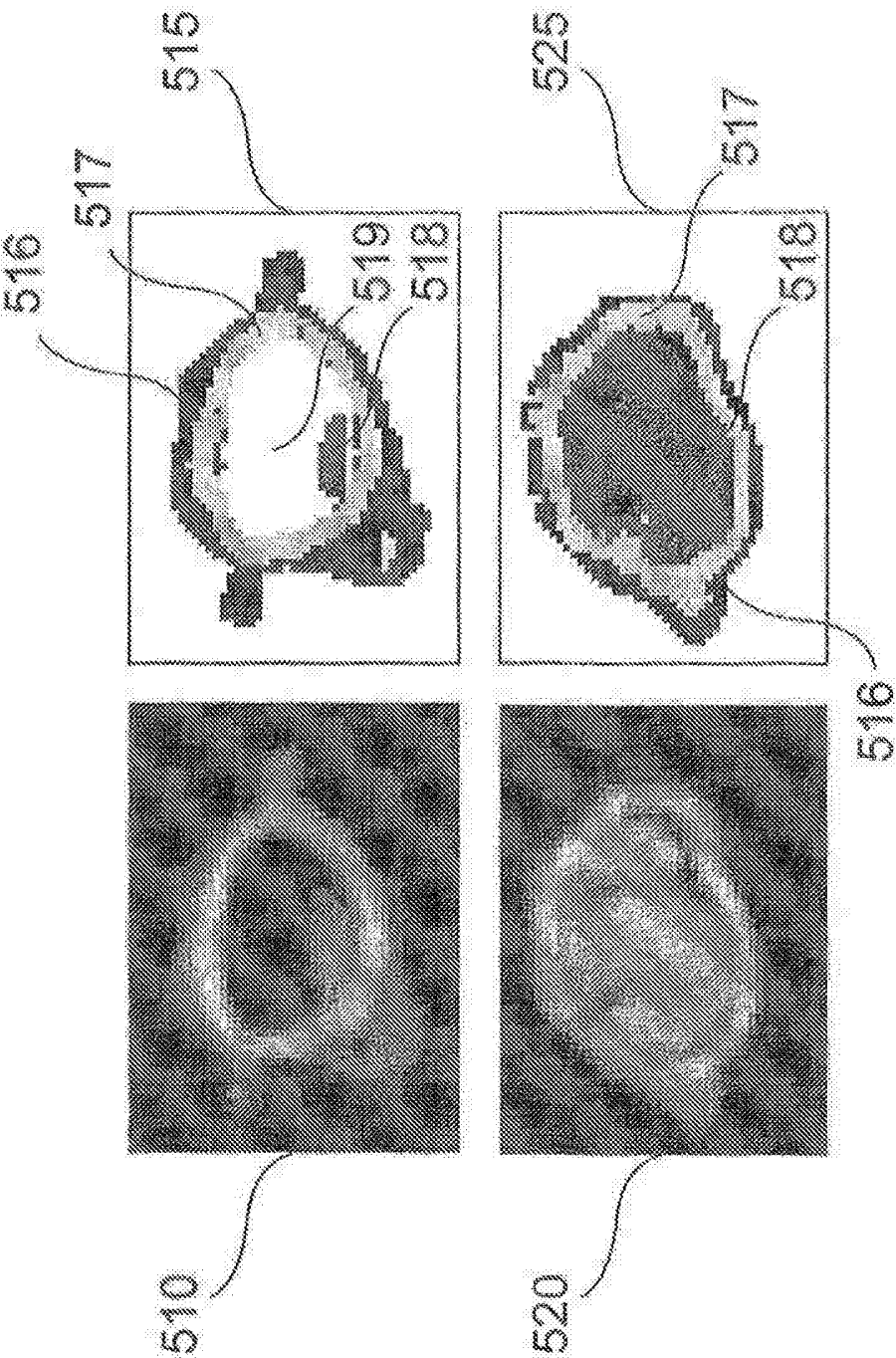


Fig. 5

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Nr.	X	Y	Z	V (mm ³)	x (mm ³)	y (mm ³)
1	202	73	69	15,41	7,23	3,44
2	277	103	69	14,91	6,88	3,37
3	353	128	69	12,21	4,70	3,20
4	133	158	69	15,12	6,51	3,48
5	212	154	69	15,22	7,31	3,32
6	281	185	69	10,68	4,48	2,57
7	357	207	69	10,97	4,25	2,73
8	438	198	69	14,54	6,41	3,50
9	111	236	69	15,43	6,93	3,62
10	191	230	69	10,71	5,25	2,46
11	326	276	69	13,27	6,56	2,59
12	406	271	69	12,29	5,25	3,00
13	77	309	69	14,13	6,57	3,40
14	158	300	69	14,71	8,11	3,23
15	235	320	69	13,27	5,93	3,35
16	304	352	69	13,22	5,39	3,17
17	384	349	69	13,14	5,99	2,93
18	163	379	69	12,03	5,71	3,01
19	239	401	69	13,35	8,19	2,31
20	314	433	69	16,50	8,59	3,56
21	202	74	142	14,94	4,92	3,95
22	276	106	142	13,42	5,16	3,93
23	352	129	142	14,84	6,42	3,83
24	131	159	142	15,72	6,57	4,17
25	211	155	142	11,71	4,50	3,41
26	280	186	142	15,19	4,98	4,47
27	357	207	142	13,36	5,94	3,45
28	437	199	142	14,82	6,04	3,96
29	110	237	142	13,70	5,16	3,84
30	191	230	142	11,73	4,60	3,25
31	325	277	142	17,12	6,83	4,34
32	405	271	142	15,77	6,76	4,14
33	77	310	142	17,48	7,18	4,23
34	157	300	142	14,00	5,82	3,78
35	234	321	142	17,28	5,82	4,62
36	303	353	142	13,71	5,79	3,33
37	383	349	142	15,28	4,93	4,13
38	163	379	142	14,93	6,19	3,72
39	238	402	142	13,87	5,60	3,63
40	313	433	142	16,03	7,04	4,31
41	200	75	217	18,37	7,47	4,43
42	275	105	217	13,94	4,82	3,75
43	350	130	217	13,45	6,13	3,50
44	130	160	217	16,75	6,86	3,85
45	209	156	217	15,73	8,02	3,82
46	279	186	217	20,45	8,95	4,73
47	354	208	217	15,17	6,47	3,73
48	436	200	217	17,40	8,20	4,13
49	108	237	217	15,84	7,16	3,83
50	189	232	217	15,66	7,56	3,73

Fig. 6

EP 2 525 641 B1

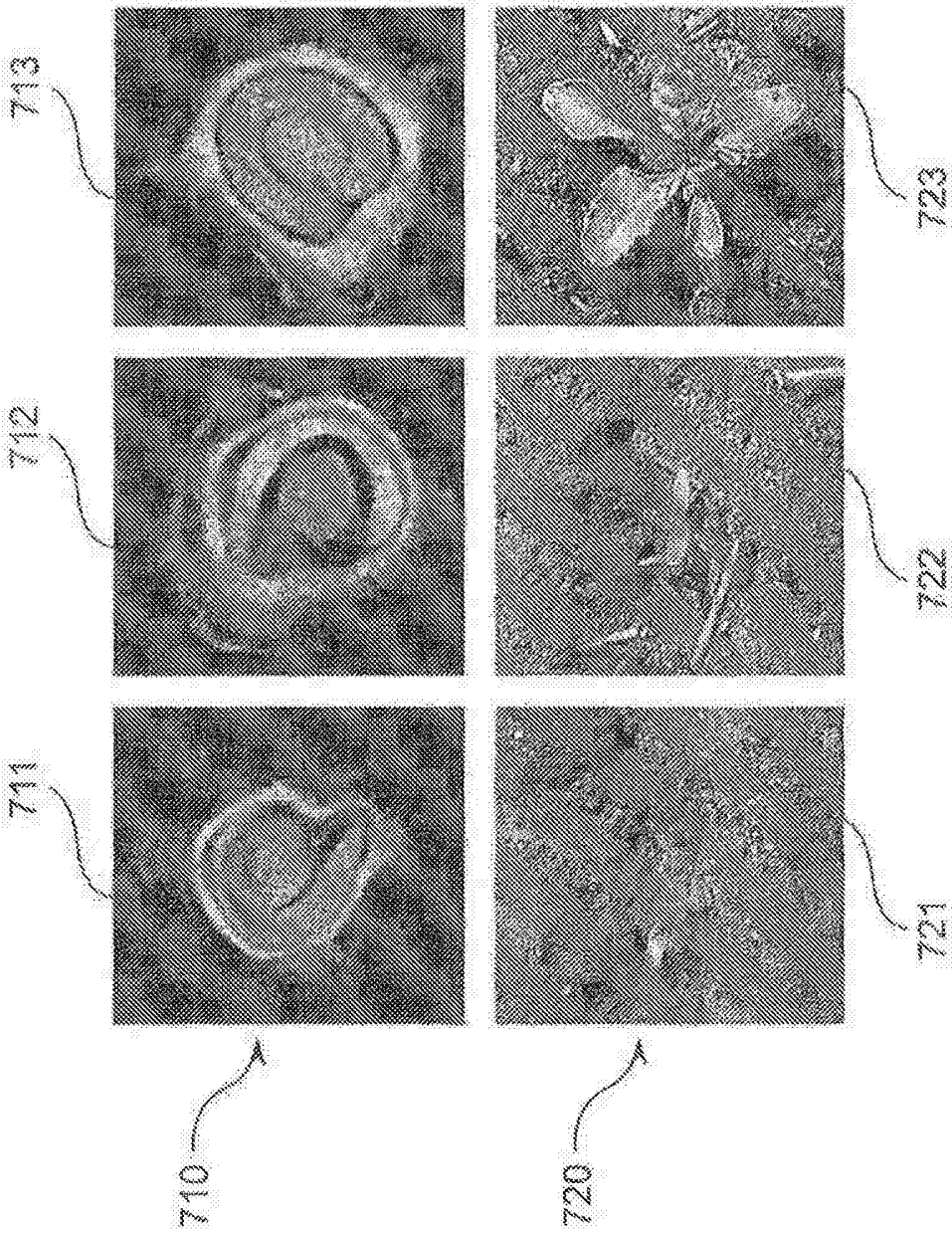


Fig. 7

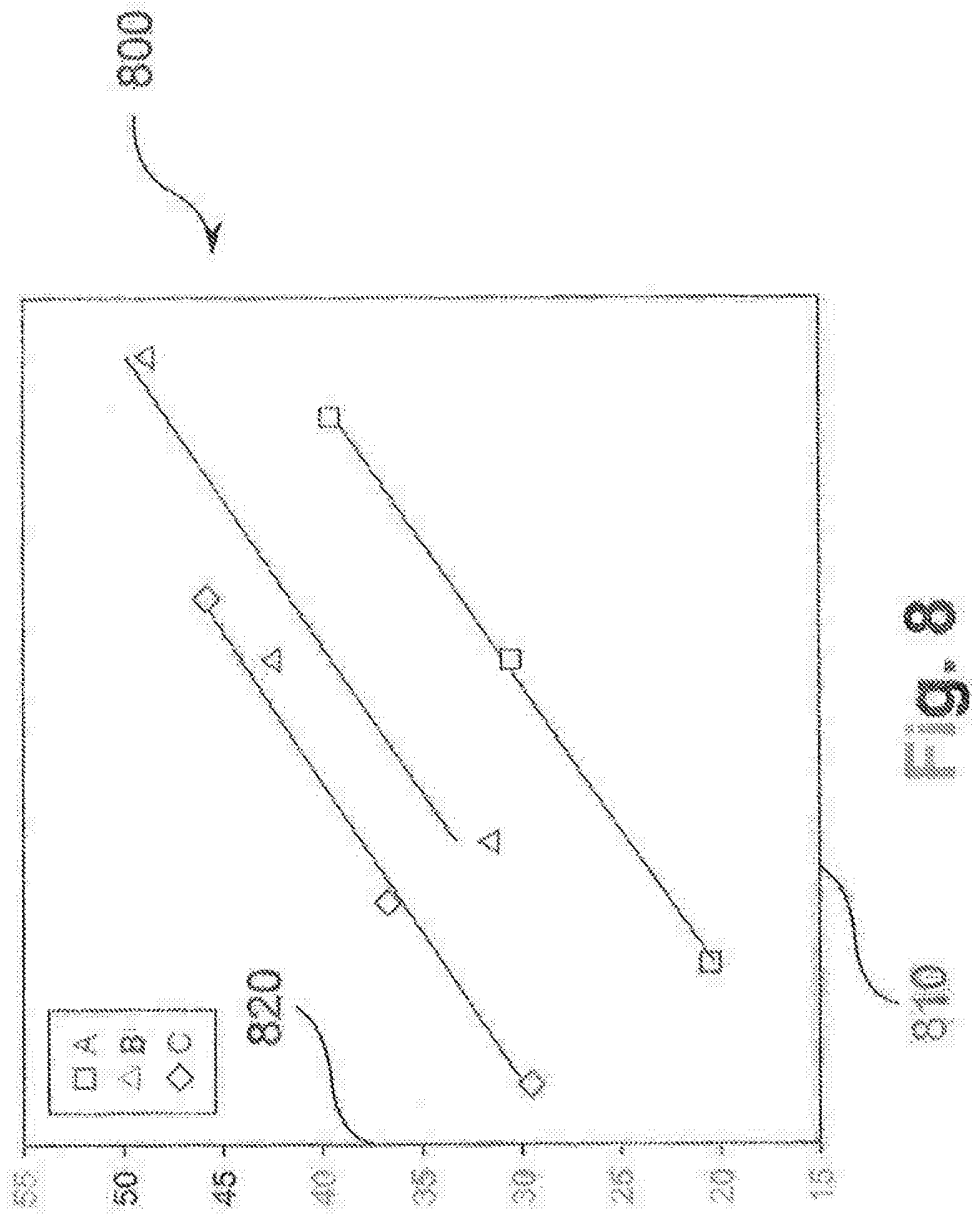


Fig. 8

EP 2 525 641 B1

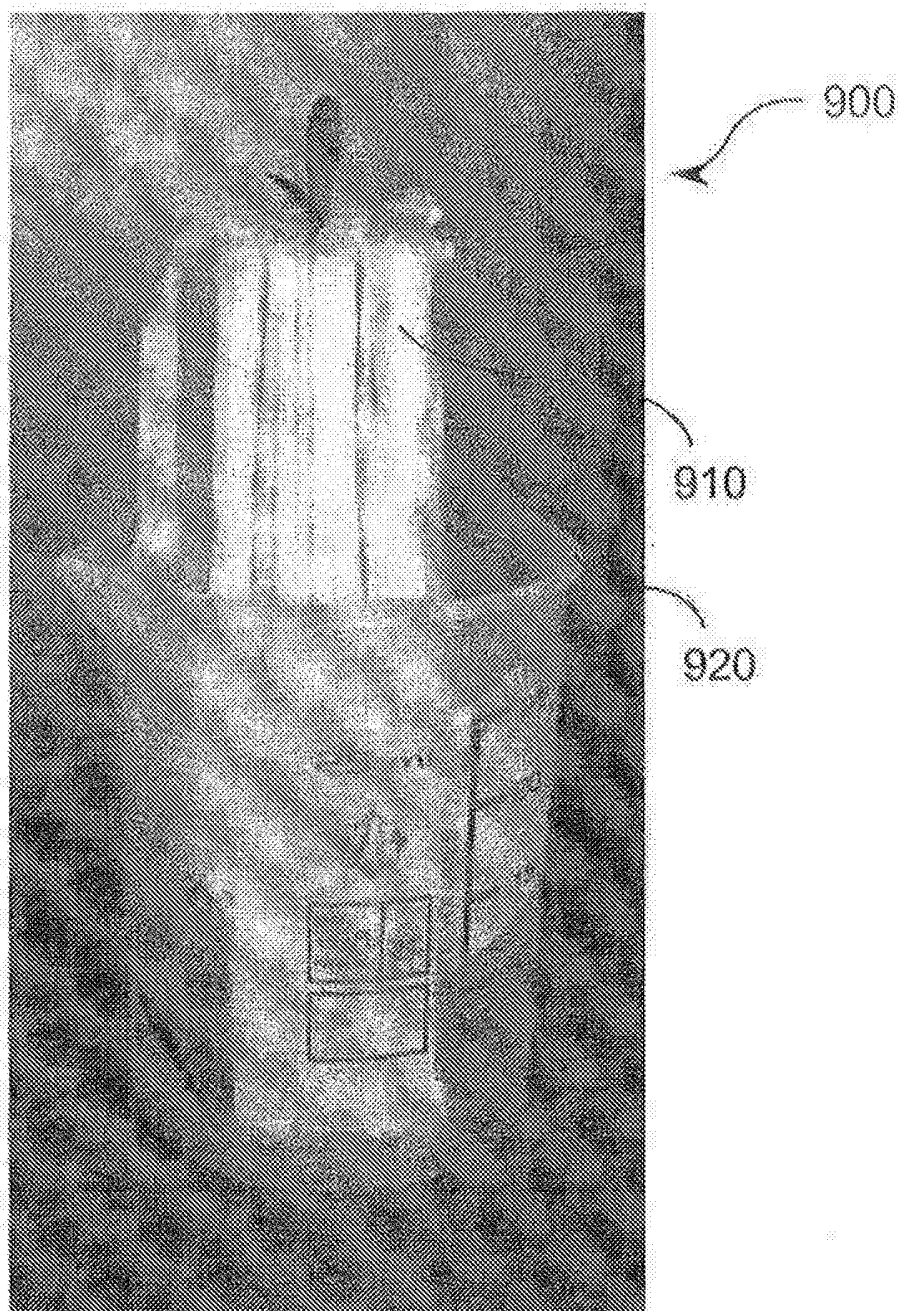


Fig. 9

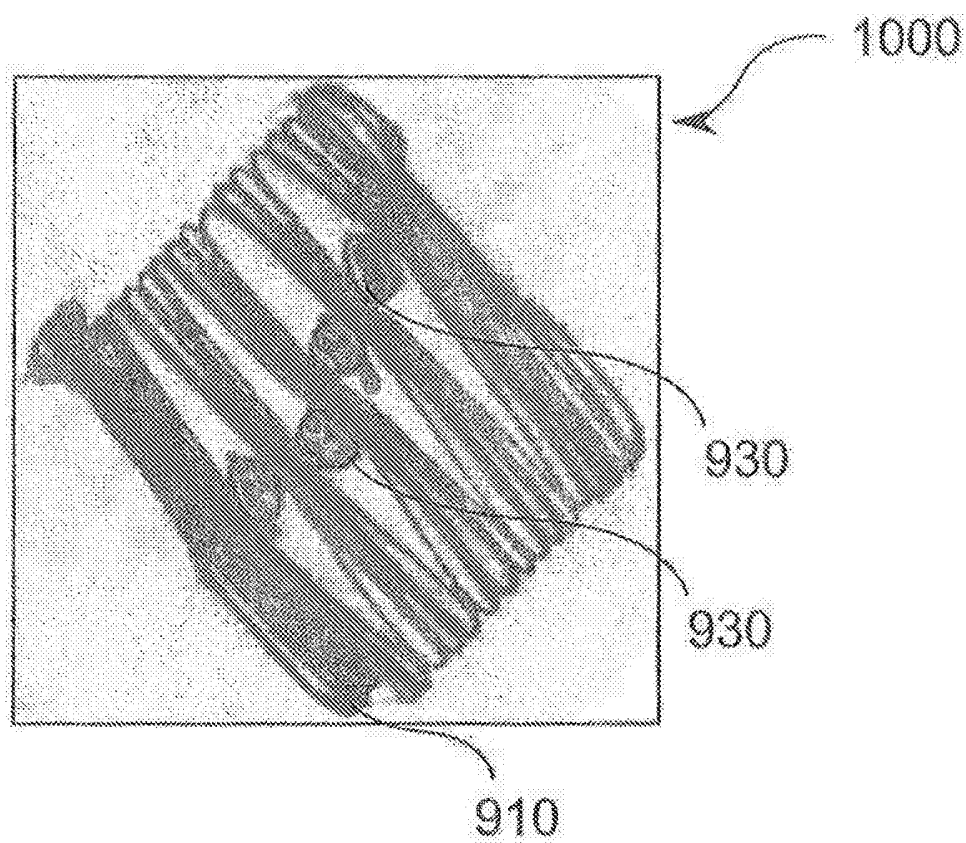


Fig. 10

EP 2 525 641 B1

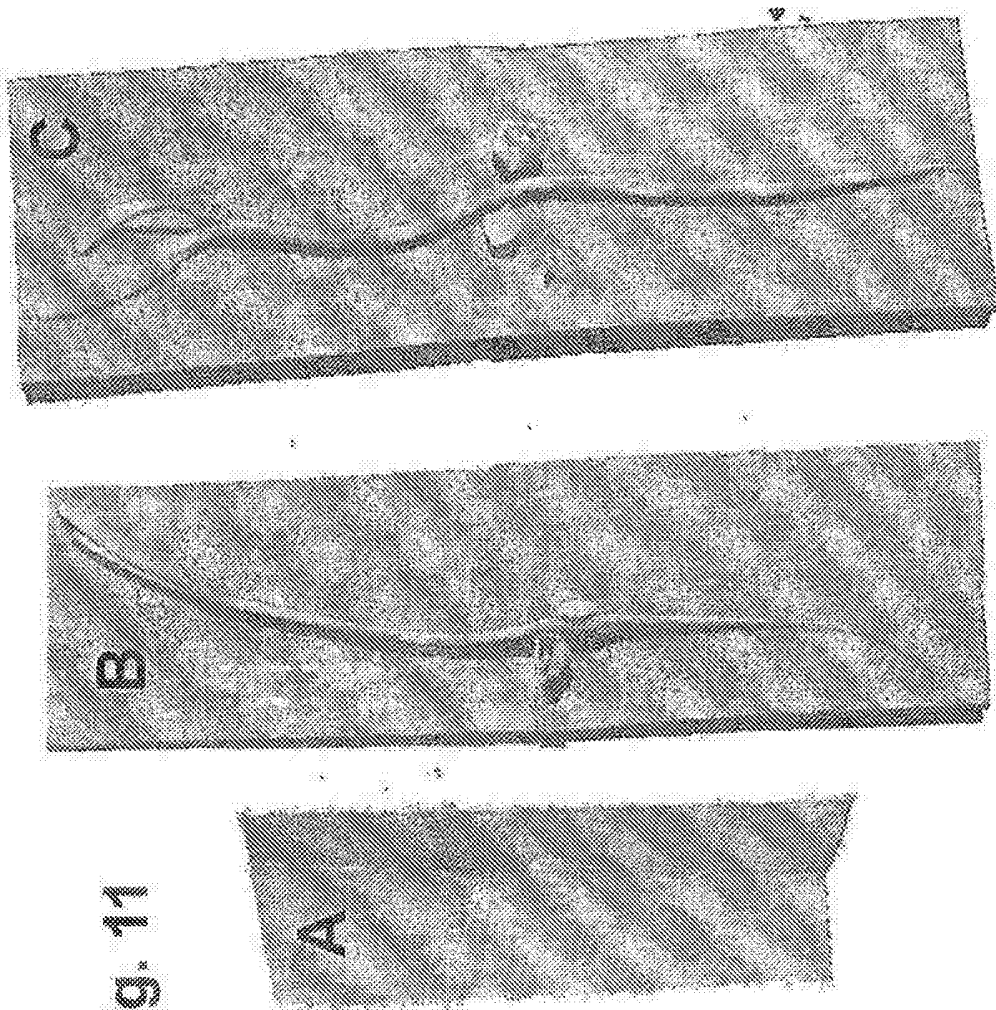


Fig. 11

EP 2 525 641 B1

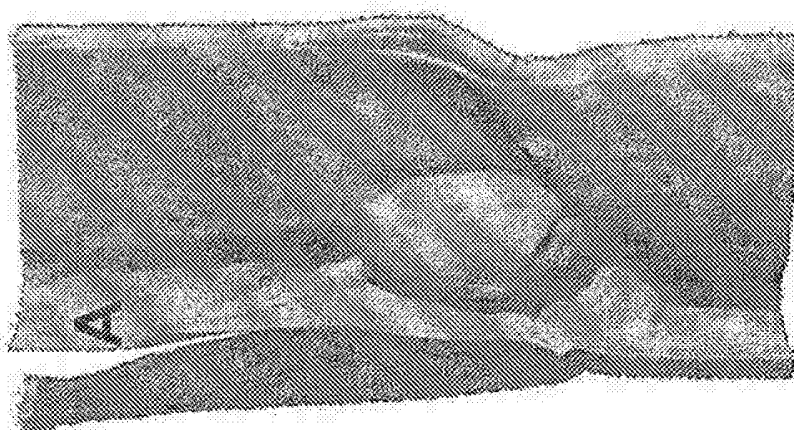
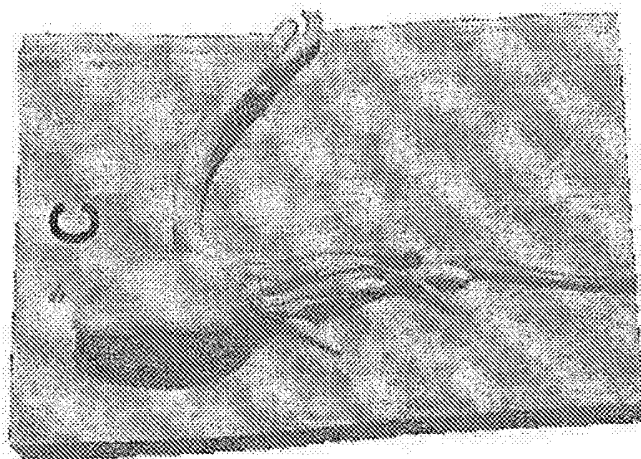
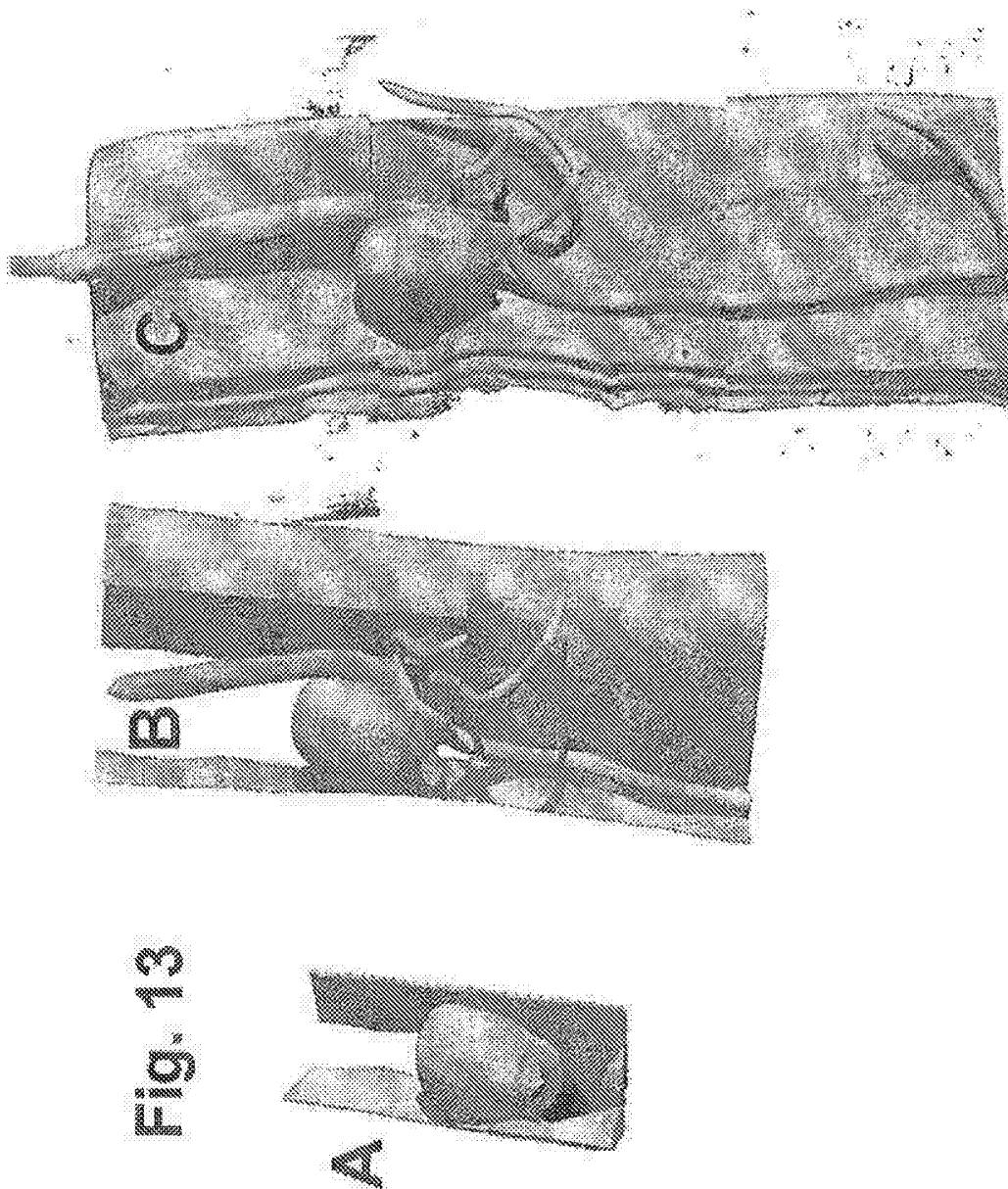


Fig. 12

EP 2 525 641 B1



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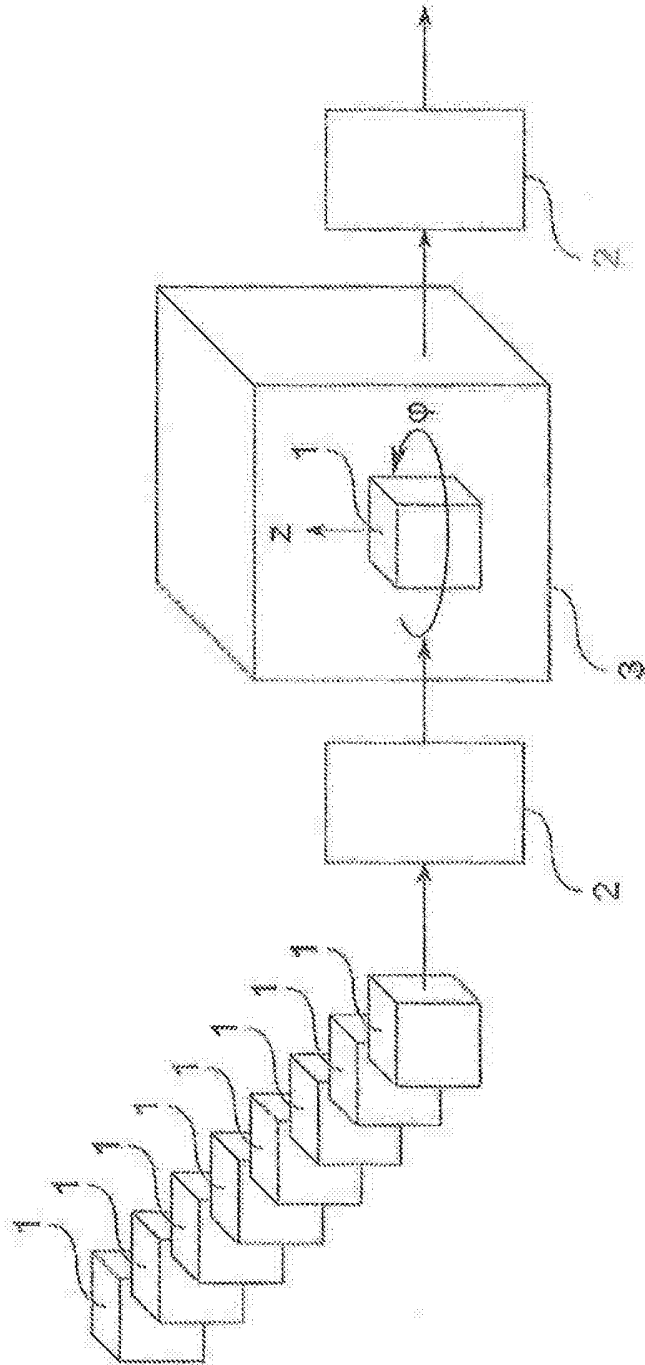


Fig. 14