SUPPLEMENT DOCUMENT FOR

"ENCAPSULATING AND REPRESENING THE KNOWLEDGE ON THE EVOLUTION OF AN ENGINEERING SYSTEM"

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APPENDIX A. TRIZ Goals

1	Weight of moving object
2	Weight of non-moving object
3	Length of moving object
4	Length of non-moving object
5	Area of moving object
6	Area of non-moving object
7	Volume of moving object
8	Volume of non-moving object
9	Speed
10	Force
11	Tension/pressure
12	Shape
13	Stability of object (resistance to change)
14	Strength
15	Durability of moving object
16	Durability of non-moving object

17	Temperature
18	Brightness
19	Energy spent by moving object
20	Energy spent by non-moving object
21	Power
22	Waste of energy
23	Waste of substance
24	Loss of information
25	Waste of time
26	Amount of substance
27	Reliability
28	Accuracy of measurement
29	Accuracy of manufacturing
30	Harmful factors acting on object
31	Harmful side-effects
32	Ease of manufacture
33	Ease of use
34	Ease of repair
35	Adaptability (to external conditions)
36	Complexity of device
37	Complexity of control
38	Level of automation
39	Productivity

APPENDIX B. TRIZ Principles

1. **Segmentation**means dividing the object into different and independent parts, so these parts can be treated separately, and different shapes can be given to them.

2. **Extraction** means removing useless part of the object or remaining just useful part of the object to use it in different systems.
3. **Local Quality** means choosing specific parts to change them or their place for efficiency.
4. **Asymmetry** means making symmetric shapes asymmetric.
5. **Combination** means pairing up processes or objects that are in the same place or happen at the same time.
6. **Universality** means avoiding the object whose function can be achieved by other object. In other words, to apply this principle, achieving multiple functions by the object is necessary.
7. **Nesting** means putting objects in objects such as Russian dolls.
8. **Counterweight** means balancing the system with the counterweight.
9. **Prior Counteraction** means reducing potential harmful effect.
10. **Prior Action** means doing things beforehand.
11. **Cushion in Advance** means making in a different way to prepare for unexpected events.
12. **Equipotentiality** means exploring in a different way to prevent fromhard work.
13. **Inversion** means making in an unconventional way.
14. **Spheroidality** means making spherical forms by challenging flat surfaces.
15. **Dynamicity** means developing systems to deal with changes from outside.
16. **Partial**, overdone or excessive action, means doing things less than or more than 100%.
17. **Moving to a new dimension** means considering a new dimension in addition to the existing ones.
18. **Mechanical vibration** means creating various effects on objects by using vibration varieties.
19. **Periodic action** means doing things periodically.
20. **Continuity of useful action**means making all components of the system to work efficiently.
21. **Rushing Through** means doing some specific jobs in a high speed level can reduce the time interval for the deformations or problems.
22. **Convert Harm to Benefit** implies that at the end of several processes there can be undesirable and harmful effects, however many industries try to use these harms as benefits. For example, harmful and waste gasses is used to heat buildings.

23. **Feedback** is sensing output of a system, processing and using the output to change events which have happened before.
24. **Mediator** means several actions, processes cannot be actualized easily so a mediator which can be added to or subtracted from the system quickly can be used for making the process easy.
25. **Self-service** implies that several devices can make actions for their selves such as maintenance and testing.
26. **Copying** can explained as using a simple copy of an entity is an appropriate option, instead of using expensive, valuable, inaccessible original.
27. **Inexpensive Short Life** can be explained as when some entities are relatively expensive or cause problems, they can be replaced with the cheaper ones that work for that moment.
28. **Replacement of a Mechanical System** is a mechanical inventor that has obligation for using some disciplines and opportunities arise for those with knowledge of other subjects, can improve the system.
29. **Use Pneumatic or Hydraulic Systems** is related to replacement solids with the liquids and gases to maintain different system properties.
30. **Flexible Film or thin membranes** can be used for having many different opportunities in systems such as low cost, space, protection necessities, flexibility and isolation.
31. **Use of porous materials** implies that porous materials allow several substances through them and block others. This allows them to be used for separating and filtering out the desirable or undesirable elements.
32. **Changing the Color** can be used for aesthetical or practical usage of the system.
33. **Homogeneity** means that same material should be used for the whole parts of the system to be more efficient.
34. **Rejecting and Regenerating Parts** are used for throwing away the unnecessary parts of the system.
35. **Transforming Physical or Chemical States** means changing several system parameters such as temperature, density.
36. **Phase Transition** implies that materials frequently go through changes, such as expanding, evaporating, or cooling which can be caused unwilling shape disorders. Therefore, to control such changes is crucial for the system.

37. **Thermal Expansion**. When the materials, components heat up, generally their shapes change.
38. **Use Strong Oxidizers** means the oxygen in the air reacts with many substances and this effect can be increased by using materials which react with oxygen more quickly or by adding more oxygen to the system.
39. **Inert Environment** means when oxygen and similar things in the environment cause problems; the solution is to take them away, or replacing them with chemicals that do not react with the system.
40. **Composite Materials**. When the same type of materials is used in the system, this can make the system deficient, so using different types of materials can make system more strong and ready to act together.

As a second tool, the contradiction matrix is a (39x39 matrix) and covers common contradictions encountered in the design of all types of systems. Also, the TRIZ principles listed in the cells of the contradiction matrix shows the appropriate solutions to the encountered contradictions.

APPENDIX C – Rehabilitation Robotics Literature

Several issues have recently emerged with respect to rehabilitation by therapists. One major health problem, that requires intensive rehabilitation is stroke, which results in giving damage on motor nerves, causing a lack of sense, and hence a disability. Traditionally, only conventional therapy through treatments by therapists was applied. However, recently, due to resource constraint on the number of therapists, and the time of doctors, the problem of patients not going through optimal therapy for the full recovery emerged as a serious challenge [1]. Another problem is that sufficient motivation can not be obtained for conventional therapy for many patients [2]. Rehabilitation robots have been developed to deal with these problems [3].Thanks to these robots, several problems encountered in traditional rehabilitation (by human therapists) can be solved to a considerable degree. Why do rehabilitation robots offer a viable alternative to physical therapy?

1) Robots can give precise and instantaneous feedback to therapists. Task-specific metrics can be monitored continuously and required modifications on the exercise routines can be applied during the therapy.

2) Robots can decrease time burden on the doctors and therapists [4]: Rehabilitation robotics are good at administering repetitive tasks of the patient while therapist remains the supervisor through the exercise. As a result, therapist can interact with multiple patients in parallel, decreasing the overall cost of the therapy.

3) Robots provide task-oriented and repetitive movements during the therapy, so patients can go through the optimal therapy. Exercises containing activities of daily living can be applied intensively with robots, which may be problematic with traditional therapy due to the physical burden of such tasks to the therapist [1][4].

4) Virtual reality applications can be incorporated into the therapy sessions, so that visual feedback is given for patients' progress through the therapy. Virtual environments not only provide faster adaptation of the recovery to real life applications, but also increase the motivation of the patient [2].

APPENDIX D

The most common wrist rehabilitation devices are developed as extension modules of task-space arm rehabilitation systems. Once such device is the wrist extension module of the MIT-Manus system [5][6]. This wrist module comprises of an actuated cardan joint coupled to a curved slider and allows for 3 DoF forearm-wrist movements. Another end-effector type wrist module exists as a part of the Robotherapist upper-extremity rehabilitation support system [7]. This system is capable of controlling all forearm-wrist rotations utilizing ER actuators for safety [8]. Exoskeleton type rehabilitation devices, on the other hand, are relatively more complex, but can be effectively used for the implementation and measurement of targeted joint movements. Armin and IntelliArm are two example exoskeleton type full-arm therapy systems, which allow for forearm supination/pronation as well as the palmar/dorsal flexion of the wrist [9][10]. These systems are also equipped with multi-axis force sensors to collect force/torque data during therapy. Other wrist robots are discussed in detail in [11].

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