TRIZ SUMMIT 2024

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Design of a parallel ankle rehabilitation robot based on TRIZ

Outline

- Problem Situation
- Problem Analysis
- Problem Solving
- Evaluation

Problem Situation

- Rehabilitation medicine, as an important part of healthcare services, is now gaining momen tum.
- Professional rehabilitation treatment and training has been playing an important role in the healing and restoration of living ability for the patients.
- Taking common ankle rehabilitation as an example
  - Many patients with ankle injuries and not enough rehabilitators
  - labour-intensive manual rehabilitation with low treatment efficiency and variability in treatment effect s
  - Existing ankle rehabilitation equipment with poor therapeutic effect, and could not satisfy the individu al needs.

MPV Analysis

MPV for ankle rehabilitation equipment:

- Versatility - can be used to rehabilitate people with different levels of disability.
- Universality - the same equipment can be used for both right and left foot.
- Flexibility - allows for multi-degree-of-freedom smooth movements, allowing for a wide variety of rehabilitation exercises.

Proposed features based on MPV:

- Individualized (for different levels of disability) rehabilitation needs;
- Interchangeable left and right feet;
- Multi-degree-of-freedom dexterous movement;

Deficiencies in existing prototype equipment

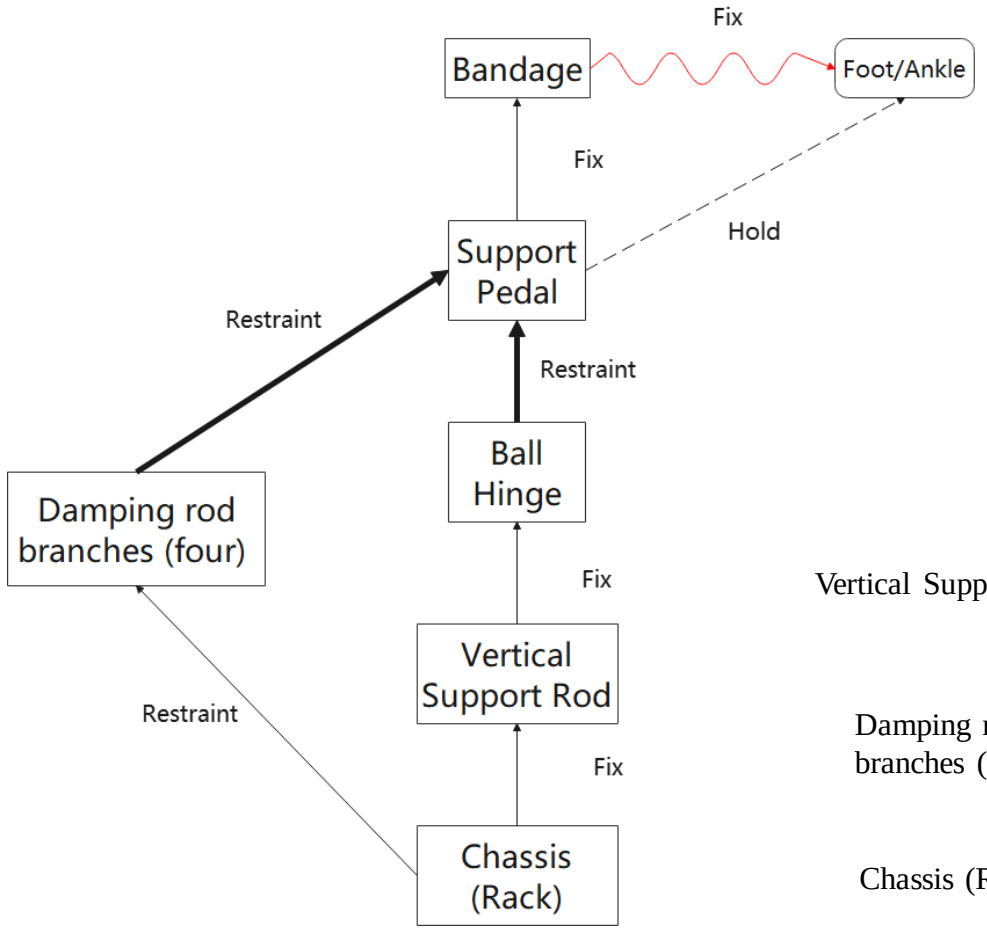
Problems with the current technical system:

- Insufficient degrees of freedom for rehabilitation (does not satisfy torsion training in three axes)
- Poor control of flexibility and angular range of motion
- Low degree of automation of the device
- Insufficient personalized adaptation (left and right foot interchangeability)
- Lack of necessary feedback

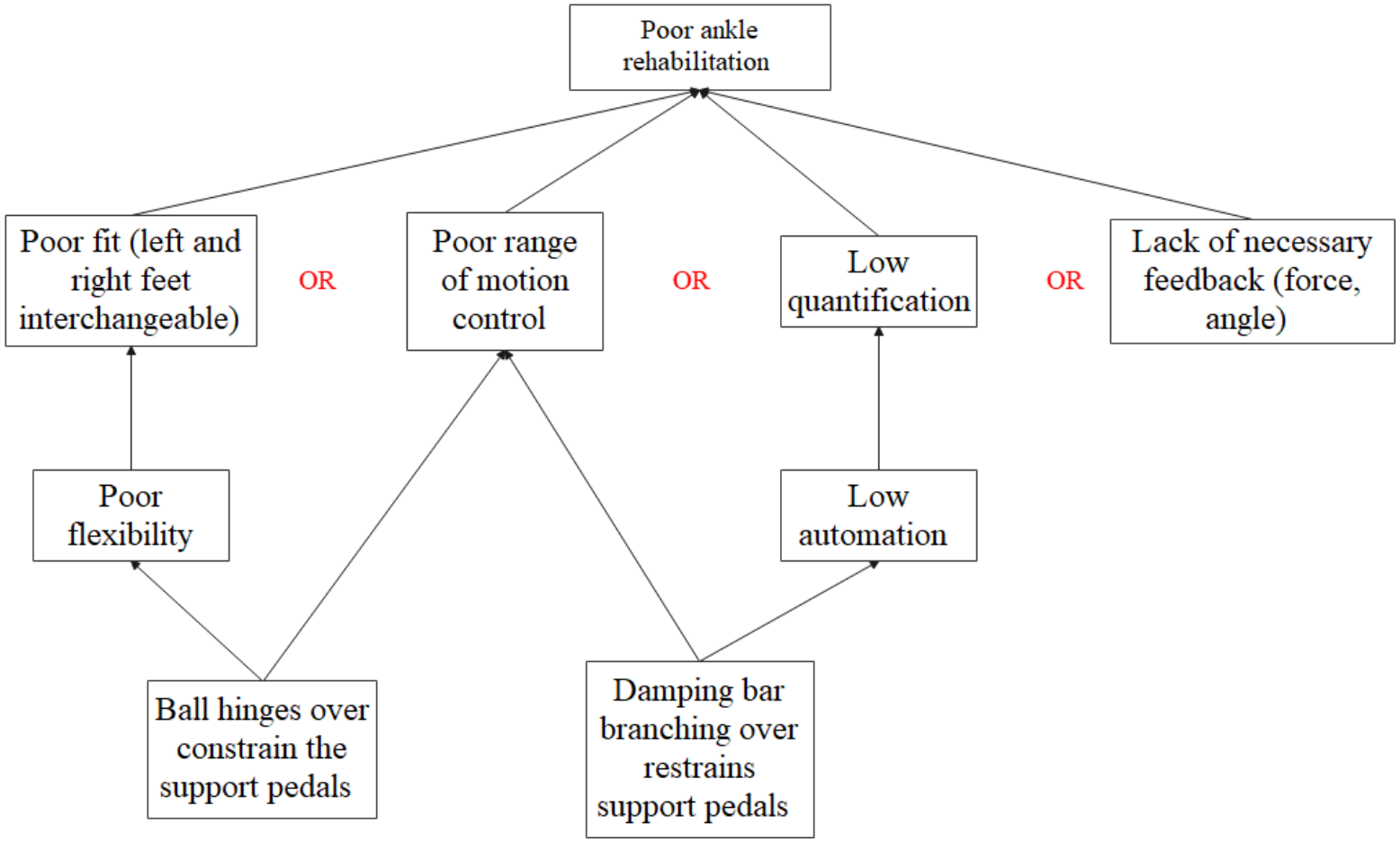
Deficiencies in existing prototype equipment (cont'd)

Existing Solution	Deficiencies
	• Time-consuming and inefficient • High labour costs • Labour-intensive • Unquantifiable rehabilitation exercises.
	• Poor flexibility/adaptability • Poor control of the angular range of mo tion • Low automation • Insufficient individualized adaptation (l eft and right foot) • Lack of feedback

Problem Analysis - Function Analysis

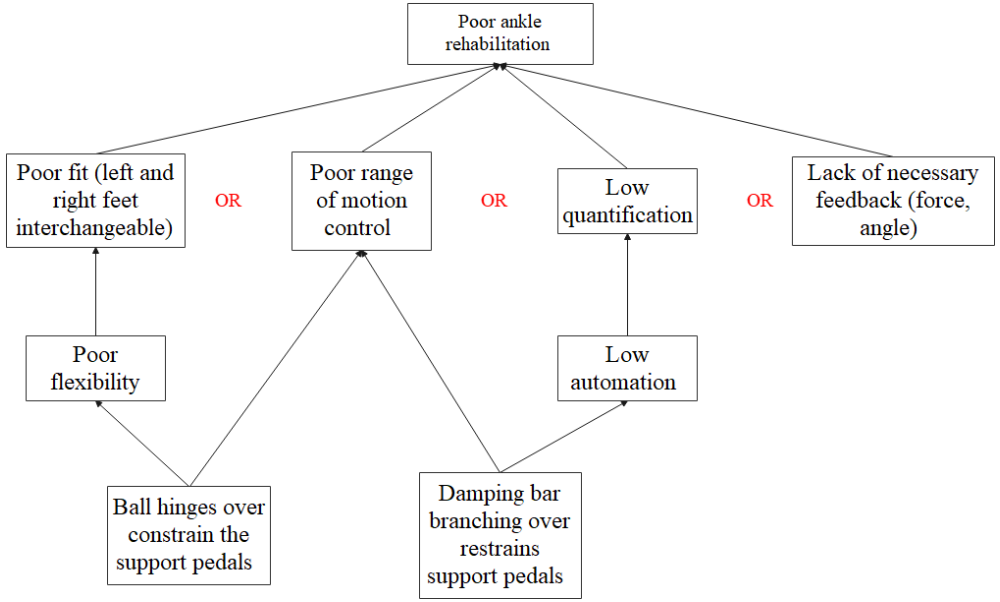


Problem Analysis - CECA



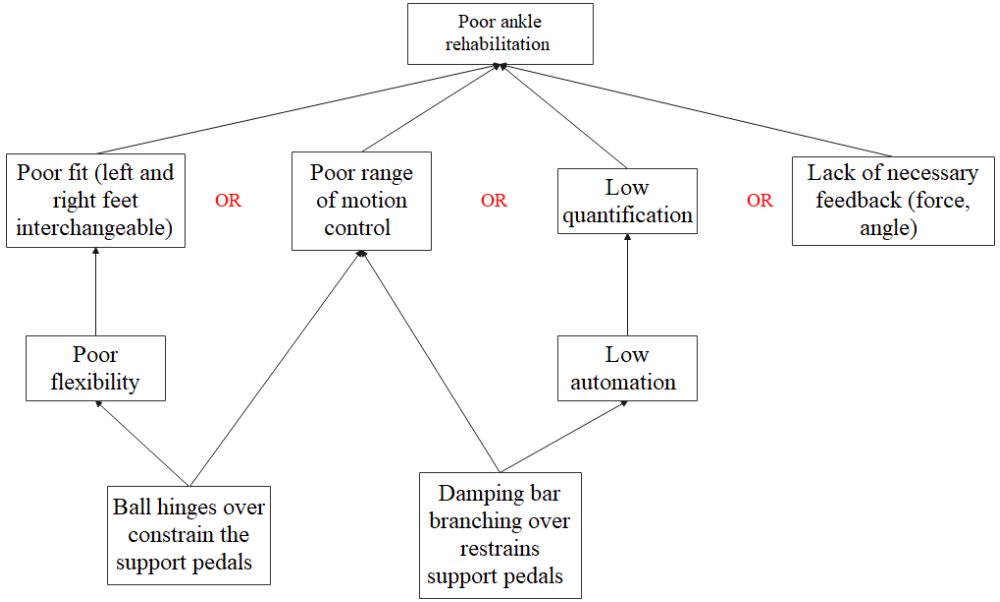
Problem Analysis - Finding Contradiction

IF	THEN	BUT	Contradiction
Adding airbag straps	Harmful factors on objects	Complexity of equipment	YES
Adding airbag straps	Harmful factors on objects	Manufacturability of equipment	YES



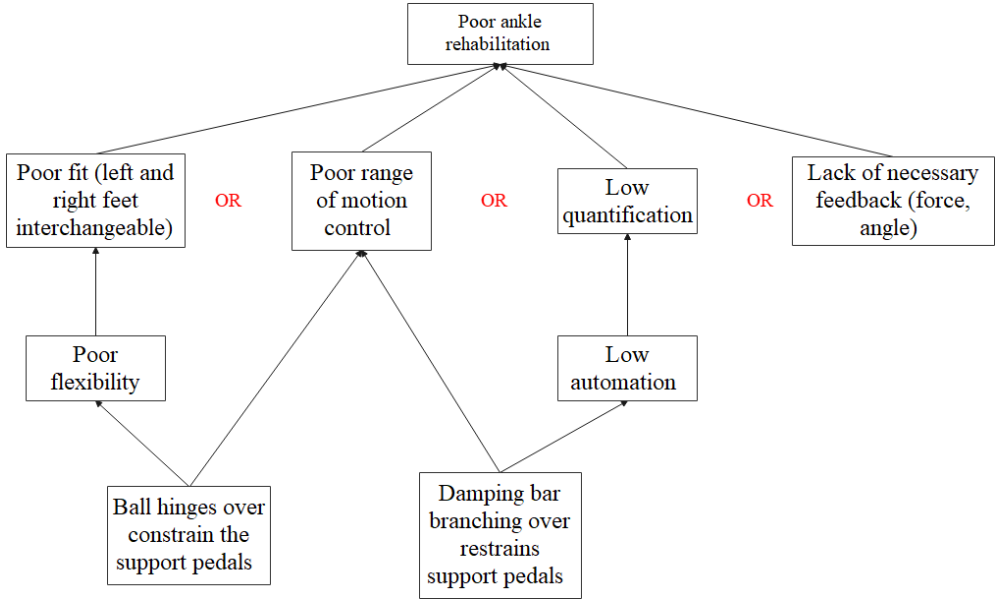
Problem Analysis - Finding Contradiction (Cont'd)

IF	THEN	BUT	Contradiction
Adding sensors	Operability	Complexity of equipment	YES
Adding sensors	Operability	Manufacturability of equipment	YES



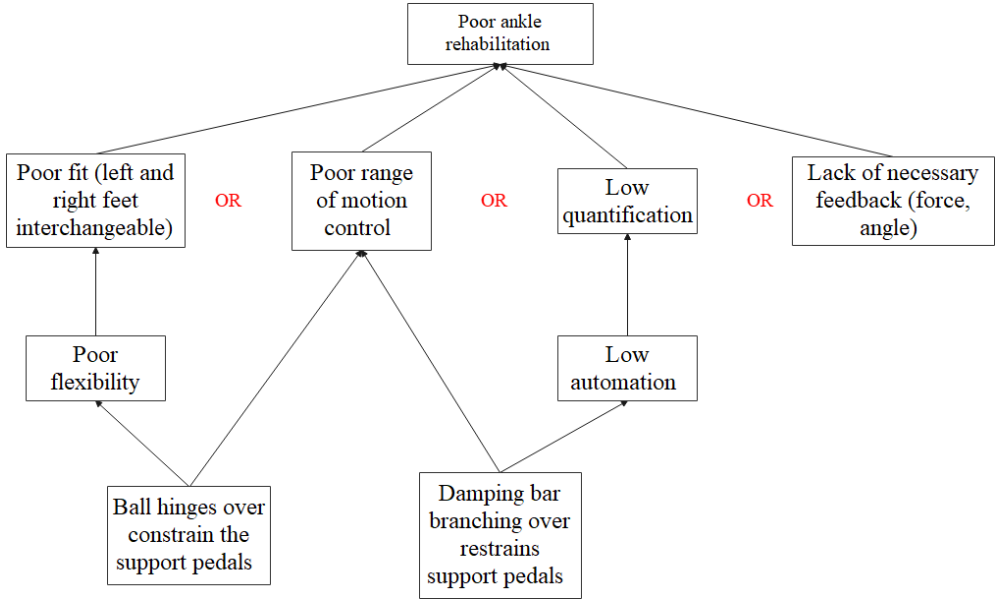
Problem Analysis - Finding Contradiction (Cont'd)

IF	THEN	BUT	Contradiction
Adding sensors	Degree of a utomation	Complexity of equipment	YES
Adding sensors	Degree of a utomation	Manufacturability of equipment	YES



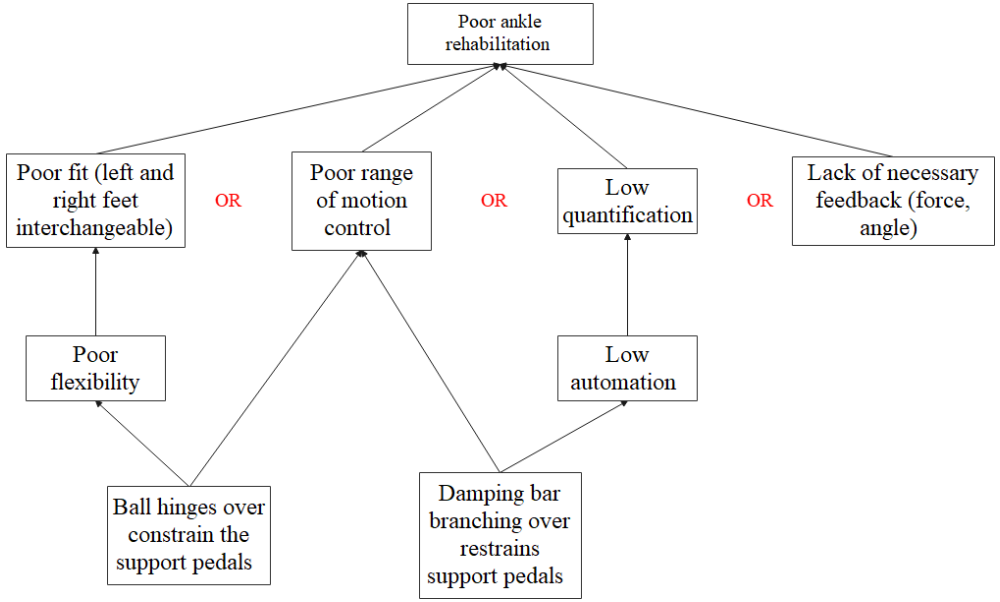
Problem Analysis - Finding Contradiction (Cont'd)

IF	THEN	BUT	Contradiction
Reducing the number of da mping rod bra nches	Complexity of equipment/Ma nufacturability of equipment	NO	NO



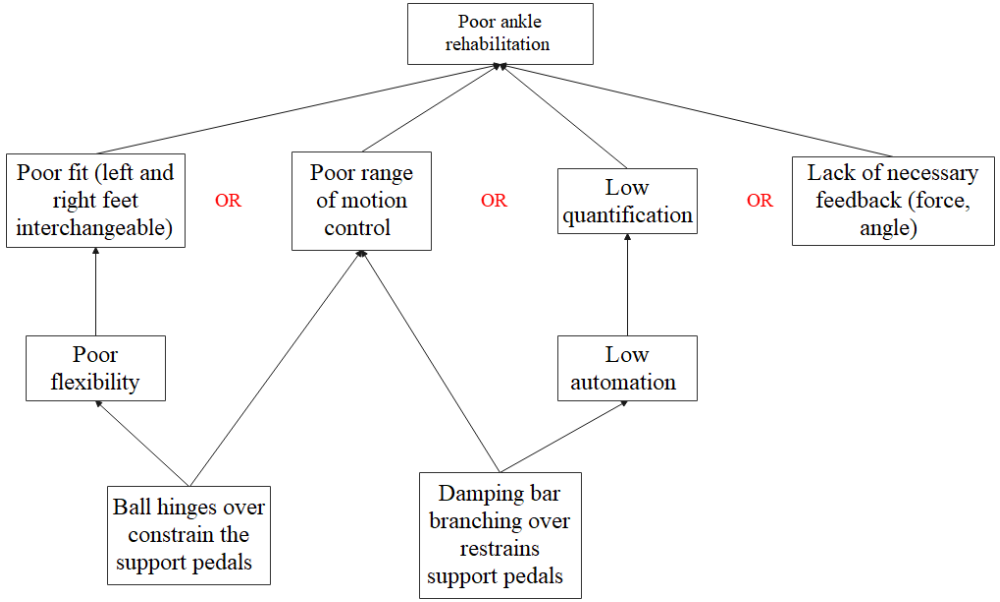
Problem Analysis - Finding Contradiction (Cont'd)

IF	THEN	BUT	Contradiction
Replacing servo-electric actuator	Degree of automation	Complexity of equipment	YES
Replacing servo-electric actuator	Degree of automation	Manufacturability of equipment	YES



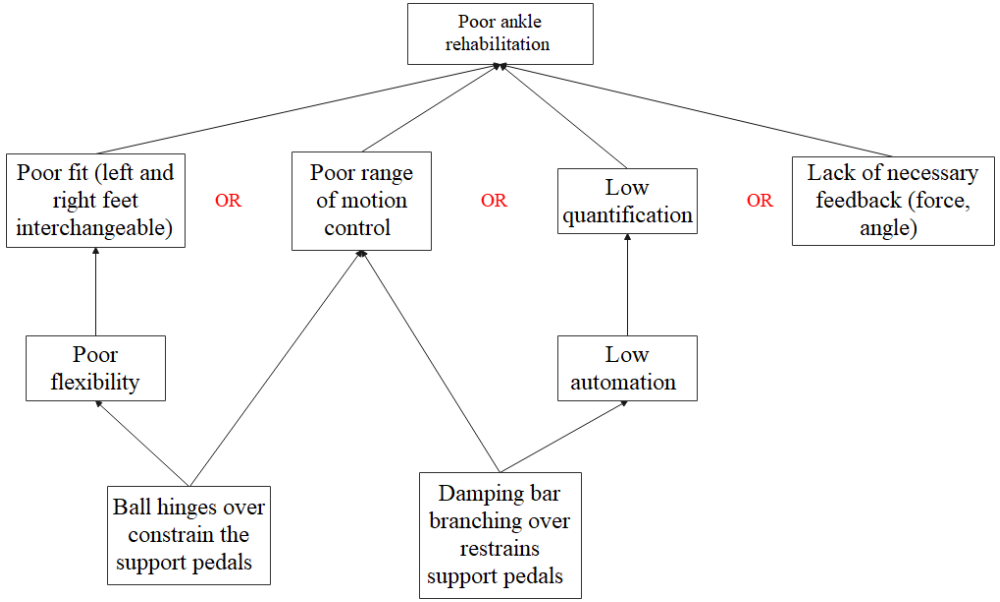
Problem Analysis - Finding Contradiction (Cont'd)

IF	THEN	BUT	Contradiction
Replacing servo-electric actuator	Operability	Complexity of equipment	YES
Replacing servo-electric actuator	Operability	Manufacturability of equipment	YES



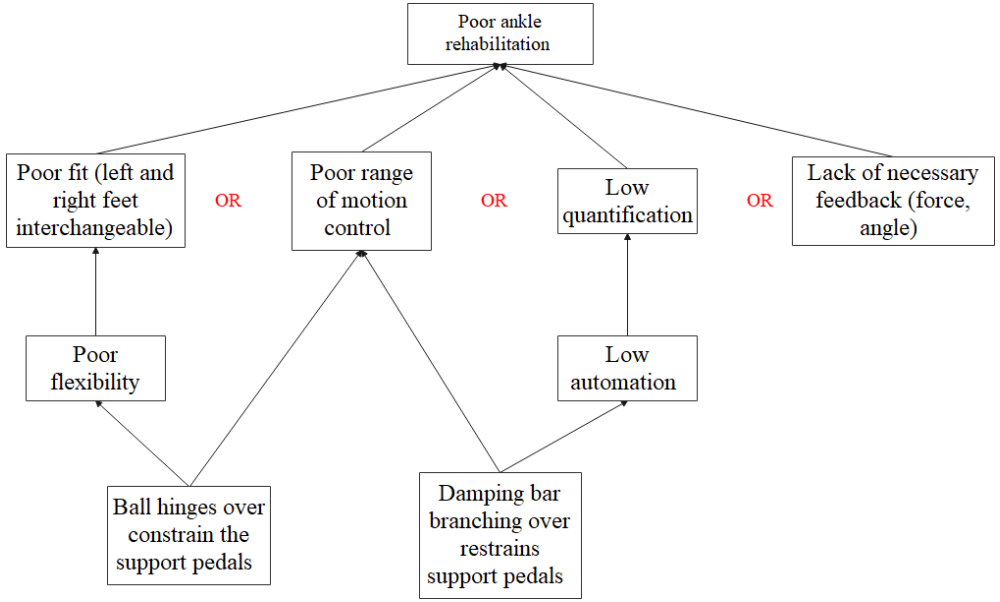
Problem Analysis - Finding Contradiction (Cont'd)

IF	THEN	BUT	Contradiction
Removing the ball hinge	Complexity of equipment/Manufacturability of equipment	NO	NO



Problem Analysis - Finding Contradiction (Cont'd)

IF	THEN	BUT	Contradiction
Addition of sli ding structures	Operability	Complexity of equipme nt	YES
Addition of sli ding structures	Operability	Manufactur ability of e quipment	YES



Problem Solving - CECA

Soultions
Solution 1: Reduce the number of damping bars.
Solution 2: Removing the ball hinge from the existing unit and support the pedal directly through the vertical support bar.

Problem Solving - Technical Contradiction

IF	THEN	BUT	Inventive Principles	Solution
Adding airbag straps	Harmful factors on objects	Complexity of equipment	22 19 29 40	Solution 3: Combine airbag strapping with traditional strapping, using airbag strapping at the point of contact with the foot/ankle joint and traditional strapping elsewhere. Solution 4: Replace the existing straps with airbag straps.

Problem Solving - Technical Contradiction (Cont'd)

IF	THEN	BUT	Inventive Principles	Solution
Adding airb ag straps	Harmful fac tors on obje cts	Manufacturability of equipment	24 35 2	Solution 5: Increase the number of airbag straps and adjust the inflation volume according to the position of the airbag straps. Solution 6: Replace the airbag straps with liquid-filled stra ps.

Problem Solving - Technical Contradiction (Cont'd)

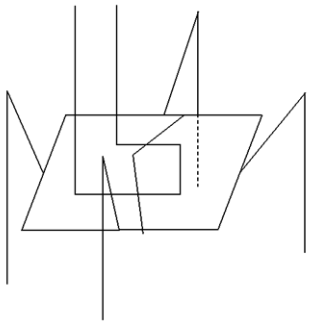
IF	THEN	BUT	Inventive Principles	Solution
Adding sensors	Operability	Complexity of equipment	32 26 12 17	Solution 7: Use a level instead of a sensor for measuring angles. Solution 8: Distinguish areas where changes in position and angle occur with distinct colours.

Problem Solving - Technical Contradiction (Cont'd)

IF	THEN	BUT	Inventive Principles	Solution
Adding sensors	Operability	Complexity of equipment	2 5 12	Solution 9: Combining multiple sensors with different roles.

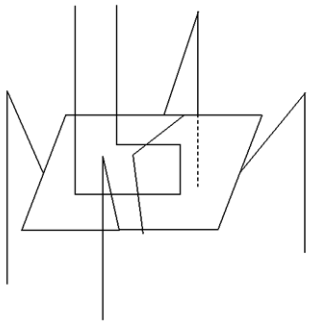
Problem Solving - Technical Contradiction (Cont'd)

IF	THEN	BUT	Inventive Principles	Solution
Adding sensors	Degree of automation	Complexity of equipment	15 10 24	Solution 10: Use memory metal for the part that comes into contact with the foot/ankle. Solution 11: Pre-tailor the device to the extent and location of the patient's injuries and adjust it to the sensor data.



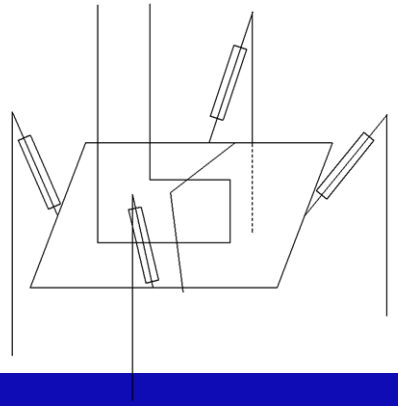
Problem Solving - Technical Contradiction (Cont'd)

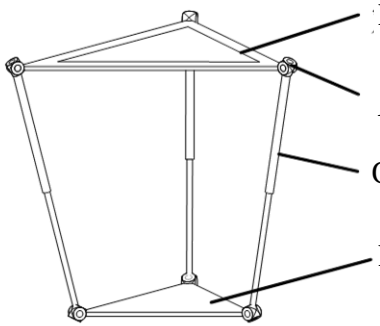
IF	THEN	BUT	Inventive Principles	Solution
Adding sensors	Degree of automation	Manufacturability of equipment	1 26 13	Solution 12: Reverse the direction of the damping rod branches and add four support rods.



Problem Solving - Technical Contradiction (Cont'd)

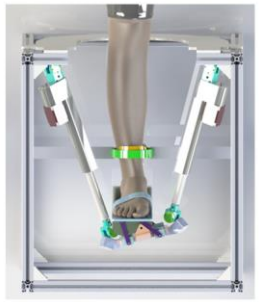
IF	THEN	BUT	Inventive Principles	Solution
Replacing servo-electric actuator	Degree of automation	Manufacturability of equipment	1 26 13	Solution 13: Reverse the direction of the servo-electric actuator and add four support rods. Solution 14: On the basis of Solution 13, the support bar is removed and replaced by a fixed platform, and the original four servo motors are reduced to three.





Problem Solving - Technical Contradiction (Cont'd)

IF	THEN	BUT	Inventive Principles	Solution
Replacing servo-electric actuator	Degree of automation	Complexity of equipment	15 10 24	Solution 15: Replace the support bar in Solution 13 with an adjustable one. Solution 16: An ankle rehabilitation mechanism based on a 3-UPU parallel mechanism by adding a foot pedal conversion device on the basis of Solution 14 to achieve left and right foot interchangeability. Solution 17: Pre-adjustment of the telescopic length of the servo-electric actuator according to the user.



Problem Solving - Technical Contradiction (Cont'd)

IF	THEN	BUT	Inventive Principles	Solution
Replacing servo-electric actuator	Operability	Complexity of equipment	32 26 12 17	Solution 18: Synchronised control of the servo-electric actuator so that the support pedal remains in the same plane at all times. Solution 19: Colour separation of the servo-electric actuator telescopic section to make changes easier to observe.

Problem Solving - Technical Contradiction (Cont'd)

IF	THEN	BUT	Inventive Principles	Solution
Replacing servo-electric actuator	Operability	Manufacturability of equipment	2 5 12	Solution 20: Combine the telescopic function of the servo-electric actuator with the vertical support rod and remove the servo-electric actuator.

Problem Solving - Technical Contradiction (Cont'd)

IF	THEN	BUT	Inventive Principles	Solution
Addition of sliding structures	Operability	Complexity of equipment	32 26 12 17	Solution 21: Increase the degrees of freedom by adding a sliding mechanism between the ball hinge and the support pedal. Solution 22: Add sliding mechanisms in different directions.

Problem Solving - Technical Contradiction (Cont'd)

IF	THEN	BUT	Inventive Principles	Solution
Addition of sliding structures	Operability	Manufacturability of equipment	2 5 12	Solution 23: Combine the sliding mechanisms of Solution 22, with different orientations.

Problem Solving - Physical Contradiction

Describing Physical Contradictions:
The number of sensors needs to be increased for getting more feedback data;
The number of sensors needs to be not increased for making the equipment simple.

Tools	Solution
Separation in time	Solution 24: Design the sensor to be detachable, which can remove it when not in use.
Separation in condition	Solution 25: Replacement of the support pedal sensor angle sensor using the branch sensor with calculation.

Problem Solving - Physical Contradiction (Cont'd)

Describing Physical Contradictions:
An inflatable bag should be added to allow the foot to be secured to the support pedal;
An inflatable bag should not be added to reduce secondary injuries caused by prolonged strangulation of the foot.

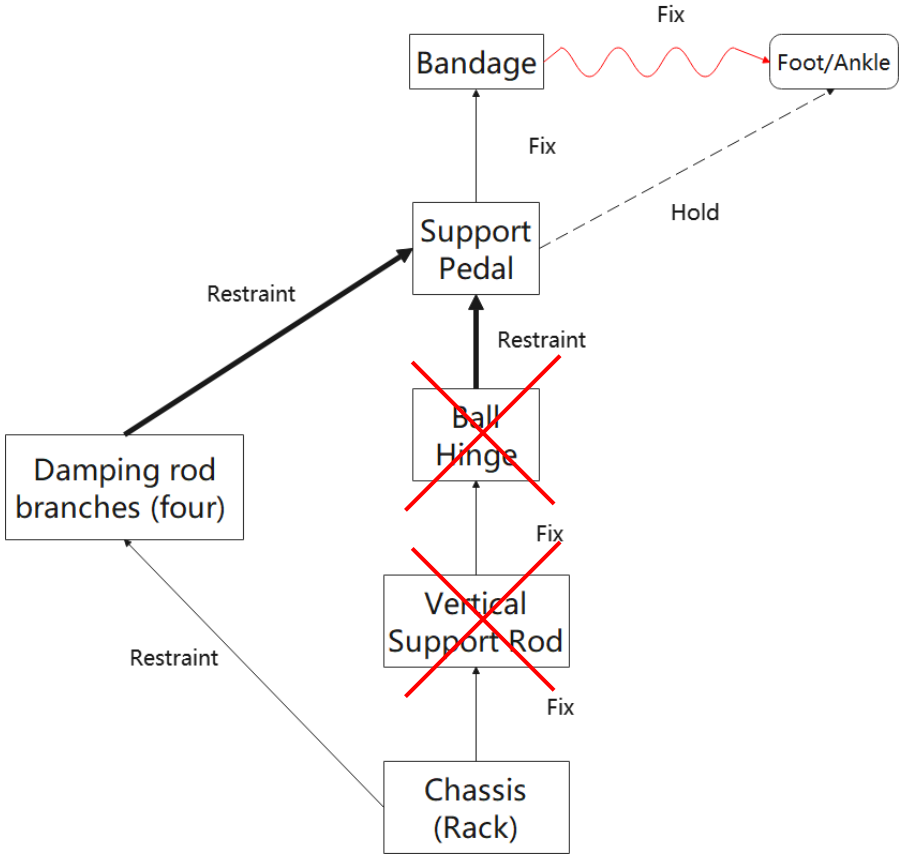
Separation method	Solution
Separation in space	Solution 26: Adjust the inflation of the airbag bandage in the corresponding position according to the force applied to the foot/ankle.
Separation in time	Solution 27: Pneumatic pressure pulsation controlled air bag (fluctuating), or controlled air pre ssure air bag bandage.
Separation in condition	Solution 28: Replacement of wide airbag straps with multiple thin airbag.

Problem Solving - Physical Contradiction (Cont'd)

Describing Physical Contradictions:
The servo actuators should be increased in order to increasing controllability;
The servo actuators should not be increased in order to reducing the complexity of the equipment.

Separation method	Solution
Separation in condition	Solution 29: Design the servo actuator as a removable structure and adjust the number of servo actuators according to the patient's condition.

Problem Solving - Trimming

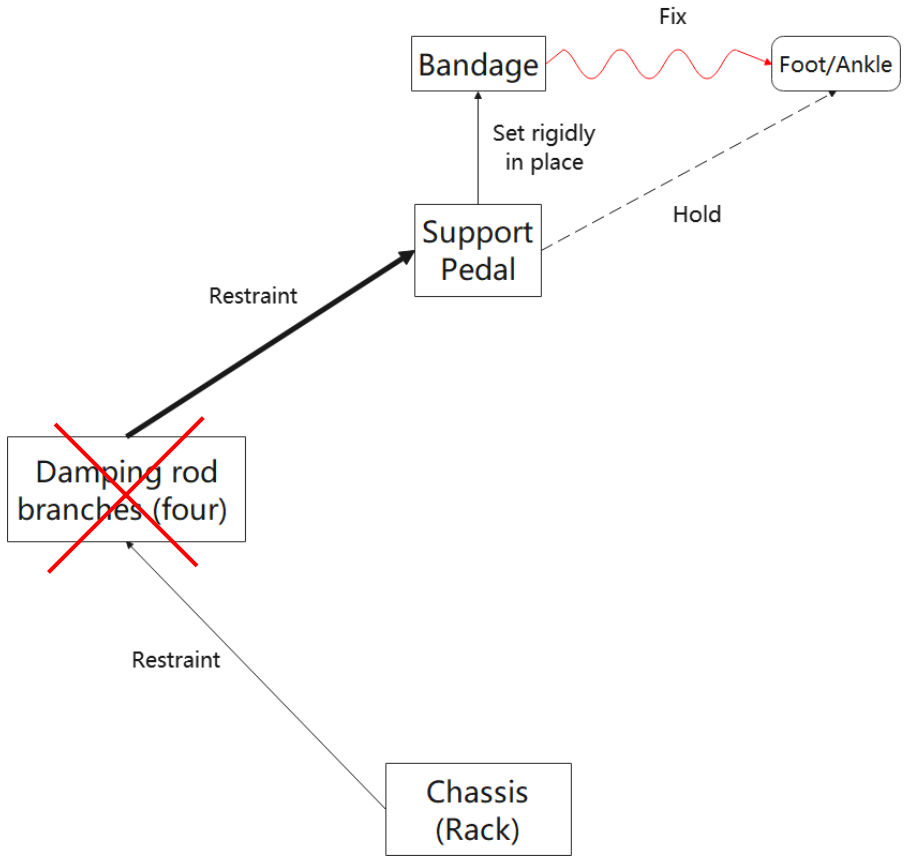


Solution

Solution 30: Removing the ball hinge and vertical support bar.

Solution 31: Use the original damping rods in the system instead of the ball-hinge su pport to support the pedals.

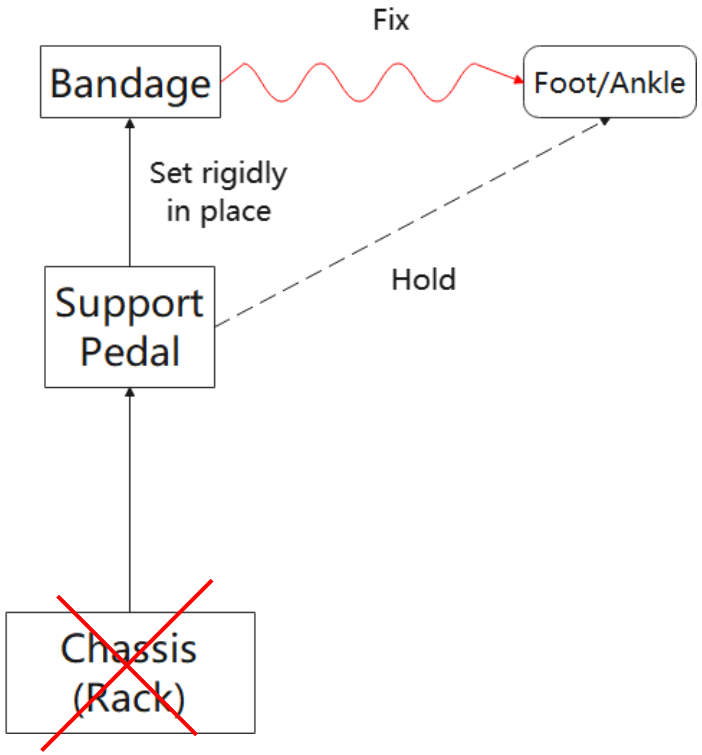
Problem Solving - Trimming (Cont'd)



Solution

Solution 32: Remove the damping rod and use a spring instead.

Problem Solving - Trimming (Cont'd)



Solution

Solution 33: Remove the base (rack).

Solution 34: Replace the support pedal with one that has a spherical bottom.

Evaluation -ABC Filtration

No.	Solution	Rank
1	Reduce the number of damping bars by reducing the original four damping bars to three.	A
2	Removing the ball hinge from the existing unit and support the pedal directly through the vertical support bar.	B
3	Combine airbag strapping with traditional strapping, using airbag strapping at the point of contact with the foot/ankle joint and traditional strapping elsewhere.	A

Evaluation -ABC Filtration (Cont'd)

No.	Solution	Rank
4	Replace the existing straps with airbag straps.	A
5	Increase the number of airbag straps and adjust the inflation volume according to the position of t he airbag straps.	B
6	Replace the airbag straps with liquid-filled straps.	A
7	Use a level instead of a sensor for measuring angles.	B

Evaluation -ABC Filtration (Cont'd)

No.	Solution	Rank
8	Distinguish areas where changes in position and angle occur with distinct colours.	B
9	Combining multiple sensors with different roles.	B
10	Use memory metal for the part that comes into contact with the foot/ankle.	C
11	Pre-tailor the device to the extent and location of the patient's injuries and adjust it to the sensor d ata.	B
12	Reverse the direction of the damping rod branches and add four support rods.	A
13	Reverse the direction of the servo-electric actuator and add four support rods.	A

Evaluation -ABC Filtration (Cont'd)

No.	Solution	Rank
14	On the basis of Solution 13, the support bar is removed and replaced by a fixed platform, and the original four servo motors are reduced to three.	A
15	Replace the support bar in Solution 13 with an adjustable one.	B
16	An ankle rehabilitation mechanism based on a 3-UPU parallel mechanism by adding a foot pedal conversion device on the basis of Solution 14 to achieve left and right foot interchangeability.	A

Evaluation -ABC Filtration (Cont'd)

No.	Solution	Rank
17	Pre-adjustment of the telescopic length of the servo-electric actuator according to the user.	B
18	Synchronized control of the servo-electric actuator so that the support pedal remains in the same plane at all times.	B
19	Colour separation of the servo-electric actuator telescopic section to make changes easier to obse rve.	B
20	Combine the telescopic function of the servo-electric actuator with the vertical support rod and re move the servo-electric actuator.	C

Evaluation -ABC Filtration (Cont'd)

No.	Solution	Rank
21	Increase the degrees of freedom by adding a sliding mechanism between the ball hinge and the support pedal.	B
22	Add sliding mechanisms in different directions.	B
23	Combine the sliding mechanisms of Solution 22, with different orientations.	B
24	Design the sensor to be detachable and remove it when not in use.	B
25	Replacement of the support pedal sensor angle sensor using the branch sensor plus calculation.	B
26	Adjust the inflation of the airbag bandage in the corresponding position according to the force applied to the foot/ankle.	B

Evaluation -ABC Filtration (Cont'd)

No.	Solution	Rank
27	Pneumatic pressure pulsation controlled air bag (fluctuating), or controlled air pressure air bag bandage.	A
28	Replacement of wide airbag straps with multiple thin airbag straps based on Solution 4.	B
29	Design the servo actuator as a removable structure and adjust the number of servo actuators according to the patient's condition.	B
30	Removing the ball hinge and vertical support bar.	B

Evaluation -ABC Filtration (Cont'd)

No.	Solution	Rank
31	Use the original damping rods in the system instead of the ball-hinge support to support the pedals.	B
32	Remove the damping rod and use a spring instead.	B
33	Remove the base (rack).	B
34	Replace the support pedal with one that has a spherical bottom.	A

Evaluation - Multi Criteria Decision Matrix

No.		Supports left and right foot swapping	Low cost	No side effects	Simple structure	Easy to operate	Totals
Weights		5	3	5	3	3	
1	Solution 1: Reduce the number of damping bars by reducing the original four damping bars to three.	-1	1	1	0	0	3
2	Solution 3: Combine airbag strapping with traditional strapping, using airbag strapping at the point of contact with the foot/ankle joint and traditional strapping elsewhere.	-1	1	0	1	1	4
3	Solution 4: Replace the existing straps with airbag straps.	-1	1	0	1	1	4

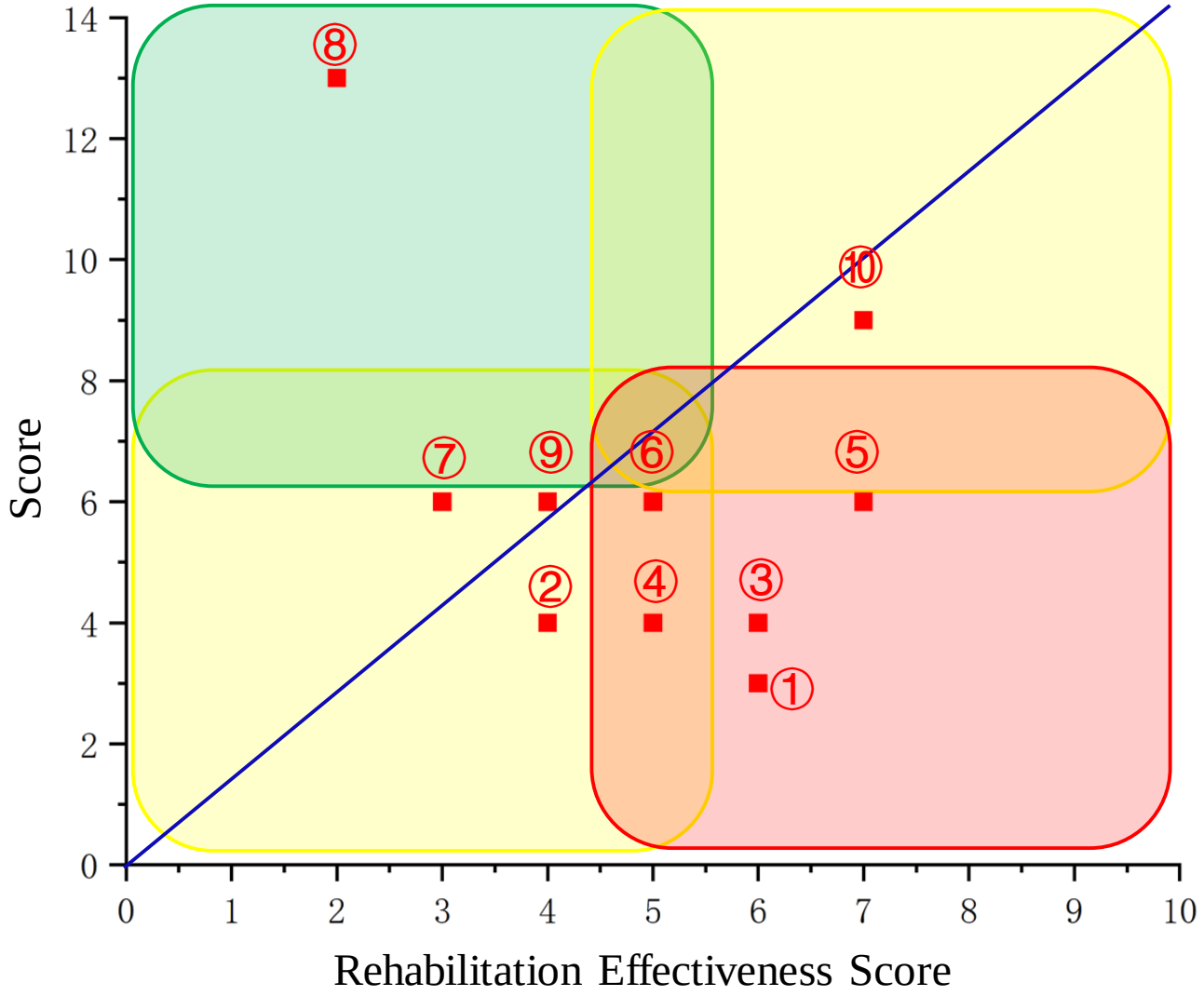
Evaluation - Multi Criteria Decision Matrix (Cont'd)

No.		Supports left and right foot swapping	Low cost	No side effects	Simple structure	Easy to operate	Totals
Weights		5	3	5	3	3	
4	Solution 6: Replace the airbag straps with liquid-filled straps.	-1	1	0	1	1	4
5	Solution 12: Reverse the direction of the damping rod branches and add four support rods.	-1	1	1	0	1	6
6	Solution 13: Reverse the direction of the servo-electric actuator and add four support rods.	-1	0	1	1	1	6

Evaluation - Multi Criteria Decision Matrix (Cont'd)

No.		Supports left and right foot swapping	Low cost	No side effects	Simple structure	Easy to operate	Totals
Weights		5	3	5	3	3	
7	Solution 14: On the basis of Solution 13, the support bar is removed a nd replaced by a fixed platform, and the original four servo motors are reduced to three.	-1	1	1	1	0	6
8	Solution 16: An ankle rehabilitation mechanism based on a 3-UPU par allel mechanism by adding a foot pedal conversion device on the basis of Solution 14 to achieve left and right foot interchangeability.	1	0	1	0	1	13
9	Solution 27: Pneumatic pressure pulsation controlled air bag (fluctuati ng), or controlled air pressure air bag bandage.	-1	0	1	1	1	6
10	Solution 34: Replace the support pedal with one that has a spherical b ottom.	0	1	0	1	1	9

Evaluation - Idea Landscaping

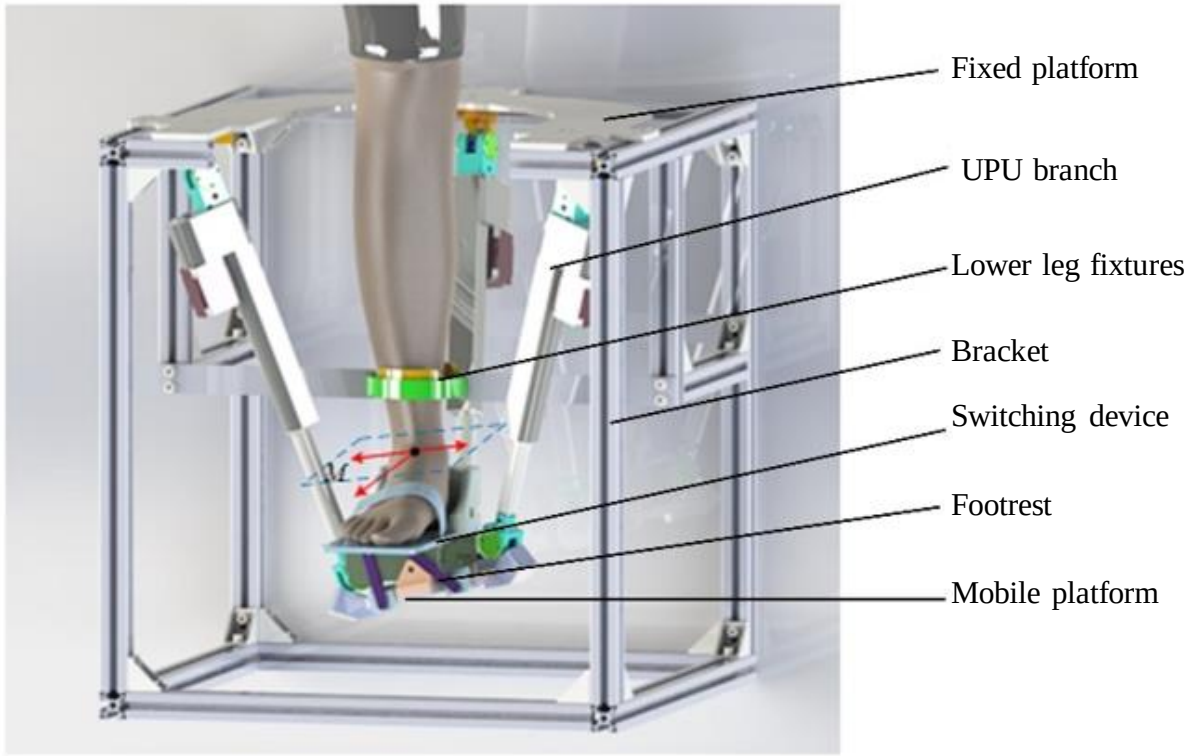


Final Solution

An ankle rehabilitation equipment based on a 3-UPU parallel mechanism with a switching device for rehabilitation of the right and left foot.

Our Innovation：

- Firstly designing of the parallel mechanism for ankle rehabilitation equipment
- Solving an important problem for rehabilitation medicine industry
- 3 Chinese patents certificate
- Successfully applied in the industry and obtained good performance



TRIZ SUMMIT 2024

Q&A SESSION

СЕССИЯ

ВОПРОСОВ И ОТВЕТОВ

TRIZ SUMMIT 2024

THANK YOU!
СПАСИБО ЗА ВНИМАНИЕ!