# FANP Study

Welcome to this FANP study. We greatly appreciate your participation! In the following, you will receive information about the background, preparation, and content of our study. The questionnaire, titled 'Local Coexisting-Cooperative-Cognitive Capabilities (Tri-Co, TCCs) Evaluation for Collaborative Robots (Cobots) from the Perspective of Cobots-Environment TCC Test Task,' aims to weight Class II TCCs indices that are included in the cobots-environment TCCs test task and that impact the cobots-environment TCCs. Before the actual questionnaire starts, you will be asked to give informed consent. The total questionnaire consists of 168 proposals to review. Completion time is anticipated to be between 90 and 120 minutes. You can complete the questionnaire across multiple sessions if you do not have the time to complete it in one sitting.

**Background information**:

Tri-Co robots are robots that can naturally interact with the working environments, humans, and other robots, autonomously adapt to complex dynamic environments, and work cooperatively. TCCs are a key feature of these robots. Cobots, a prime example of Tri-Co robots, have received significant attention and found wide application. Since 2015, the World Robot Contest-Tri-Co Robots Challenge for Cobots has been successfully held for nine sessions. During the contest, the expert committee focuses on the comprehensive evaluation of TCCs of cobots, a significant yet insufficiently addressed issue. Most research on performance evaluation of cobots has not yet achieved the local evaluation of TCCs from the perspective of test tasks. Therefore, we aim to weight Class II TCCs indices that impact the cobots-environment TCCs, which are defined as Tri-Co performance evaluation indices and have the indirect evaluation attribute of transforming the TCCs of cobots from qualitative to quantitative.

**Preparation**:

We have already organized several brainstorming sessions with some experts from the competition's expert committee and designed the cobots-environment TCCs test task. This includes the steps, description, and scoring standards of the cobots-environment TCCs test task. Details are provided in the following section titled 'Information of Cobots-Environment TCCs Test Task.' Based on this cobots-environment TCCs test task, we are now soliciting opinions from experts in related fields to weight Class II TCCs indices that impact the cobots-environment TCCs.

**Content**:

Using the improved fuzzy analytic network process (IFANP) and triangular fuzzy numbers (TFN), experts need conduct pairwise comparisons of elements (Class II TCCs) and element groups (scoring standards) under the premise of the cobots-environment TCCs test task. The ultimate goal is to obtain the priorities of each Class II TCCs indices within the IFANP network, that is, the weight vectors.

# Informed Consent Agreement

**Study Title**: Local TCCs Evaluation for Cobots from the Perspective of Cobots-Environment TCCs Test Task.

Please read this consent agreement carefully before you decide to participate in the study.

**Consent Form Key Information**: Participate in survey study about weighting Class II TCCs indices included in cobots-environment TCCs test task that impact the cobots-environment TCCs. Take this survey over a period of 1 weeks (time per survey: 90-120 minutes).

**Purpose of the research study**: The study aims to weight Class II TCCs indices included in cobots-environment TCCs test task that impact the cobots-environment TCCs.

**What you will do in the study**: In this study, based on the improved fuzzy analytic network process (IFANP) and triangle fuzzy numbers (TFN), you will be asked to conduct pairwise comparisons of elements (Class II TCCs) and element groups (scoring standards) under the premise of cobots-environment TCCs test task.

**Data Collected**: We will collect your pairwise comparisons results. During this survey, you may skip any question that makes you uncomfortable and/or stop the survey at any time. However, we appreciate your expert opinion and hope you will be able to complete as much as possible.

**Time Required**: The study will require about 1.5 hours of your time.

**Risks**: There are no anticipated risks in this study.

**Benefits**: There are no direct benefits to you for participating in this research study.

**Confidentiality**: Your data will only be released anonymously, which means that your name will not be linked to the data. Your survey data will be recorded, stored, and shared anonymously using an individually assigned identification number.

**Voluntary participation**: Your participation in the study is completely voluntary.

**Right to withdraw from the study**: You have the right to withdraw from the study at any time without penalty. How to withdraw from the study: If you would like to withdraw, please contact Jing Zhao (zhaojing@bjut.edu.cn). You do not have to indicate a reason for withdrawal. There is no penalty for withdrawing. Answers that have already been submitted will not be deleted.

**Payment**: You will receive no payment for participating in the study.

**Using data beyond this study**: The researcher would like to make the information collected in this study available to other researchers in some case after the study is completed. The researcher will remove any identifying information (such as your name, contact information, etc.) connected to the information you provide. Aggregated and anonymous data will be shared with other researchers for future studies. You will not be asked to give your permission for each new study, as your name and other information that could potentially identify you nor will they attempt to identify you will not be shared.

**If you have questions about the study, please contact**:

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**Agreement**: I agree to participate in the research study described above. By selecting 'yes' below, I agree to participate in this survey. I understand the nature of the study and I am participating voluntarily. I understand that I can withdraw at any time, without any penalty or consequences.

☐ Yes

☐ No

## Information of Cobots-Environment TCCs Test Task

A schematic of this test task is shown in Fig. 1.

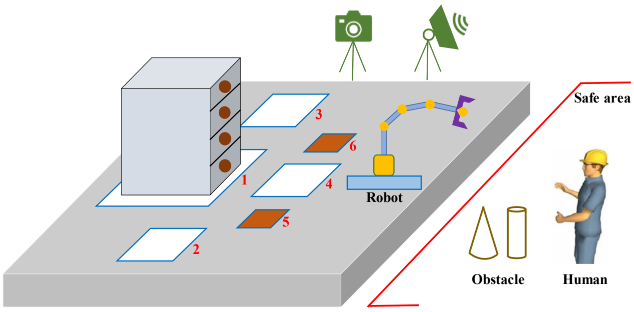


**Fig. 1 – Cobots-environment TCCs test task diagrammatic sketch.**

**Steps of the cobots-environment TCCs test task:**

(1) The cobot was equipped with auditory sensors and learned voice datasets to receive voice commands from humans.

(2) The cobot was equipped with visual sensors to learn the characteristics of the three types of objects, as shown in Fig. 2.

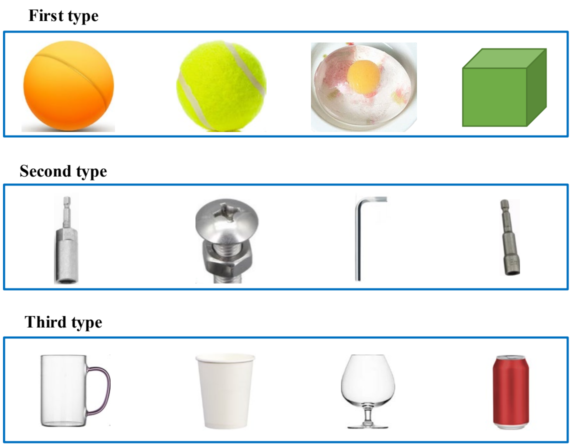


**Fig. 2 – Three types of objects with different characteristics.**

(3) The person gave a voice command indicating the object to be grasped and the corresponding placement area. The cobot recognised the voice command and searched for the object to be grasped in the four compartments.

(4) The cobot performed motion planning in an unstructured environment, opened a compartment to grab objects and placed them in a designated area. When the interaction between the compartments prevented the cobot from grasping smoothly, it was necessary to autonomously adjust the relative position of the compartments until the object was grasped smoothly.

(5) When step (4) was being performed, the person randomly placed cylindrical and conical obstacles in areas 5 and 6. The cobot should identify and stop the operation on time, wait for obstacles to be placed. After the person entered the safe area, the cobot continued obstacle avoidance planning. The object was then placed.

(6) Repeated items (1) to (5) until the cobot grasps all three types of objects and places them in the designated area.

**Description of the cobots-environment TCCs test task:**

(1) Before the test task began, the person randomly selected three compartments from the four compartments to place three types of objects.

(2) Voice commands: area 2 corresponded to the number "2", area 3 corresponded to the number "3", and area 4 corresponded to the number "4"; the first type of object corresponded to the number "7", the second type of object corresponded to the number "8", and the third type of object corresponded to the number "9".

(3) The cobot knew the information of the objects and the layout information of the work area but did not know the type of objects placed in each compartment.

(4) The cobot should be arranged in a position where it can complete a test task.

(5) The cobot should independently choose adaptive impedance control or intelligent control methods according to the characteristics of different objects. During the operation of the cobot, the Kalman filter algorithm or adaptive complementary filter algorithm should be selected independently for pose estimation.

**Scoring standards of the cobots-environment TCCs test task:**

(1) Each time a voice command was successfully recognised and an object was correctly grasped, two points were added.

(2) Two points were added to each successfully placed object.

(3) If the cobot did not collide with the humans, 16 points were added. If the cobot did not collide with the cylinder or the cone, 10 points were assigned.

(4) Ten points were added if the cobot stopped suddenly after colliding with a person without causing harm.

(5) If the average completion time was at (0, 10] min, 10 points would be added to the total score; at (10, 12] min, 6 points would be added to the total score; and at (12, 15] min, 2 points would be added. No points were awarded if the average completion time exceeded 15 min.

(6) This test task needs to be completed three times; the assignment scores plus the reward scores generated by the average completion time, the arithmetic means of the sum of the two were taken as the total score. If the total score exceeded 100, the total score was regarded as 100.

The scoring records of this test task experiment are listed in Table 1.

**Table 1 – Scoring records.**

| **Scoring requirements** | **Scores** |
|---|---|
| Successfully recognised voice commands and correctly grasped objects | |
| Successfully placed object | |
| No collision with obstacles | |
| Stopped quickly after colliding with people without causing harm to them | |
| Reward | |

## Questionnaire Template

The questionnaire, titled 'Local TCCs Evaluation for Cobots from the Perspective of Cobots-Environment TCCs Test Task,' aims to weight Class II TCCs indices which impact the cobots-environment TCCs. Based on the improved fuzzy analytic network process (IFANP), a comprehensive evaluation model is developed, as shown in Table 2.

**Table 2 - Technical parameter evaluation indices.**

| Scoring indices | Sub-indices | Explaination |
|---|---|---|
| Successfully recognised voice commands ( $U_1$ ) | Multimodal information fusion and processing ( $u_{11}$ ) | This refers to the integration and processing of data from multiple sources and types (e.g., visual, auditory, tactile) to improve decision-making or control in robotics. |
| Successfully opened the compartments ( $U_2$ ) | Modeling of work environment ( $u_{21}$ ) | This involves creating a digital or conceptual model of the working environment where the robot operates, which can include factors like layout, obstacles, and interaction zones. |
| | Motion planning in an unstructured environment ( $u_{22}$ ) | This is the process of determining a path or series of actions for a robot to execute within an environment that lacks a predefined structure, often dealing with unpredictable elements. |
| | Hybrid force/position control ( $u_{23}$ ) | A control strategy used in robotics that combines force and position control to manipulate objects with precision, especially useful in environments where both the position of the robot and the forces it applies are important. |
| Successfully searched for the object to be grasped in the four compartments ( $U_3$ ) | Multimodal information fusion and processing ( $u_{31}$ ) | This refers to the integration and processing of data from multiple sources and types (e.g., visual, auditory, tactile) to improve decision-making or control in robotics. |
| | Motion planning in an unstructured environment ( $u_{32}$ ) | This is the process of determining a path or series of actions for a robot to execute within an environment that lacks a predefined structure, often dealing with unpredictable elements. |
| Correctly grasped objects ( $U_4$ ) | Hybrid force/position control ( $u_{41}$ ) | A control strategy used in robotics that combines force and position control to manipulate objects with precision, especially useful in environments where both the position of the robot and the forces it applies are important. |
| | Adaptive impedance control ( $u_{42}$ ) | A dynamic control method where a robot automatically adjusts its impedance (stiffness and damping) to adapt to different interaction scenarios with the environment or humans. |
| | Intelligent control ( $u_{43}$ ) | Refers to the use of advanced algorithms, including artificial intelligence techniques, to enhance the autonomy and decision-making capabilities of robots. |
| | Kalman filtering algorithm ( $u_{44}$ ) | A statistical algorithm used to estimate the state of a linear dynamic system from a series of incomplete and noisy measurements. Commonly used in robotics for real-time localization and navigation. |
| Successfully placed object ( $U_5$ ) | Modeling of work environment ( $u_{51}$ ) | This involves creating a digital or conceptual model of the working environment where the robot operates, which can include factors like layout, obstacles, and interaction zones. |
| | Motion planning in an unstructured environment ( $u_{52}$ ) | This is the process of determining a path or series of actions for a robot to execute within |

| | | |
|---|---|---|
| | | an environment that lacks a predefined structure, often dealing with unpredictable elements. |
| | Real-time obstacle avoidance ( $u_{53}$ ) | This involves detecting and maneuvering around obstacles in real time to prevent collisions, crucial for autonomous robot navigation. |
| No collision with humans ( $U_6$ ) | Real-time obstacle avoidance ( $u_{61}$ ) | This involves detecting and maneuvering around obstacles in real time to prevent collisions, crucial for autonomous robot navigation. |
| | Collision avoidance ( $u_{62}$ ) | Specifically focuses on strategies and systems that prevent the robot from colliding with objects or humans by predicting potential collisions and modifying the robot's path or behavior. |
| No collision with obstacles ( $U_7$ ) | Real-time obstacle avoidance ( $u_{71}$ ) | This involves detecting and maneuvering around obstacles in real time to prevent collisions, crucial for autonomous robot navigation. |
| | Collision avoidance ( $u_{72}$ ) | Specifically focuses on strategies and systems that prevent the robot from colliding with objects or humans by predicting potential collisions and modifying the robot's path or behavior. |
| | Collision detection ( $u_{73}$ ) | The process of identifying when a robot has made contact with an object or another robot, which is important for tasks involving physical interaction. |
| Stopped quickly after colliding with people without causing harm to them ( $U_8$ ) | Real-time obstacle avoidance ( $u_{81}$ ) | This involves detecting and maneuvering around obstacles in real time to prevent collisions, crucial for autonomous robot navigation. |
| | Collision detection ( $u_{82}$ ) | Specifically focuses on strategies and systems that prevent the robot from colliding with objects or humans by predicting potential collisions and modifying the robot's path or behavior. |

The structured network model is established as shown in Fig. 3.

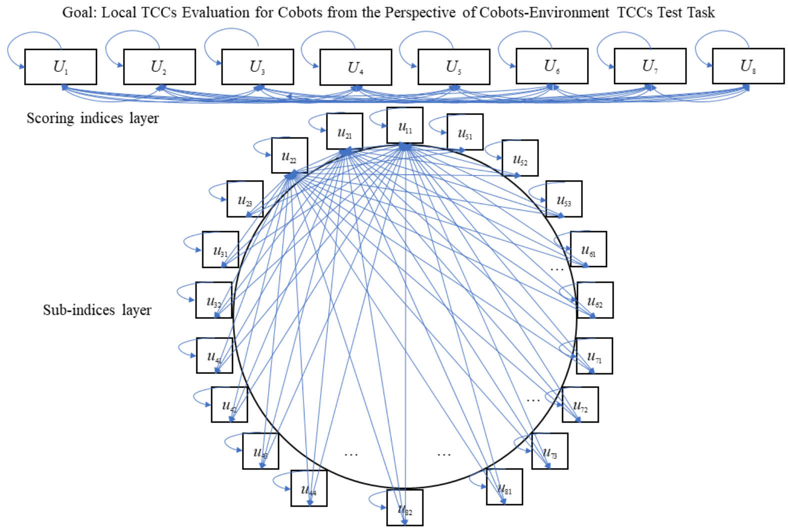


**Fig. 3 - The structured analytic network system.**

According to the above models, experts are asked to weight different indices in two networks based on the definition of linguistic scale and corresponding triangle fuzzy numbers (TFN). For experts' convenience in pairwise comparisons, abbreviated notations can be used, as shown in Table 3.

**Table 3 - Triangular fuzzy scale used in our IFANP.**

| Linguistic scale for importance | Triangular fuzzy scale | Reciprocal triangular fuzzy scale |
|---|---|---|
| Just equal | (1 / 2, 1, 3 / 2) (a) | (2 / 3, 1, 2) (a') |
| Weakly more important | (5 / 2, 3, 7 / 2) (c) | (2 / 7, 1 / 3, 2 / 5) (c') |
| Strongly more important | (9 / 2, 5, 11 / 2) (e) | (2 / 11, 1 / 5, 2 / 9) (e') |
| Very strongly more important | (13 / 2, 7, 15 / 2) (g) | (2 / 15, 1 / 7, 2 / 13) (g') |
| Absolutely more important | (17 / 2, 9, 19 / 2) (v) | (2 / 19, 1 / 9, 2 / 17) (v') |

Notes: (3 / 2, 2, 5 / 2) (b), (7 / 2, 4, 9 / 2) (d), (11 / 2, 6, 13 / 2) (f), (15 / 2, 8, 17 / 2) (h), and the reciprocals of their triangular fuzzy numbers (that is b', d', f', and h') denote intermediate values of the adjacent judgments above. Meanwhile, we use (w) to represent (1, 1, 1) .

An example of pairwise comparison is provided for experts as shown in Table 4. If you believe that, under the criterion of element group $U_6$ , $U_3$ is weakly more important compared to $U_2$ , please write 'c' and 'c'' in the corresponding blank, as shown in Table 4.

**Table 4 - Pairwise comparisons of element groups under the criterion of $U_6$ .**

| Expert ( ) | $U_6$ | $U_1$ | $U_2$ | $U_3$ | $U_4$ | $U_5$ | $U_6$ | $U_7$ | $U_8$ |
|---|---|---|---|---|---|---|---|---|---|
| | $U_1$ | | | | | | | | |
| | $U_2$ | | | c' | | | | | |
| | $U_3$ | | c | | | | | | |
| | $U_4$ | | | | | | | | |
| | $U_5$ | | | | | | | | |
| | $U_6$ | | | | | | | | |
| | $U_7$ | | | | | | | | |
| | $U_8$ | | | | | | | | |

## Pairwise comparison between element groups

**Table 5 - Pairwise comparisons between element groups under the criterion of $U_1$ .**

| Expert ( ) | $U_1$ | $U_1$ | $U_2$ | $U_3$ | $U_4$ | $U_5$ | $U_6$ | $U_7$ | $U_8$ |
|---|---|---|---|---|---|---|---|---|---|
| | $U_1$ | | | | | | | | |
| | $U_2$ | | | | | | | | |
| | $U_3$ | | | | | | | | |
| | $U_4$ | | | | | | | | |
| | $U_5$ | | | | | | | | |
| | $U_6$ | | | | | | | | |
| | $U_7$ | | | | | | | | |
| | $U_8$ | | | | | | | | |

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**Table 6 - Pairwise comparisons between element groups under the criterion of $U_8$ .**

| Expert ( ) | $U_8$ | $U_1$ | $U_2$ | $U_3$ | $U_4$ | $U_5$ | $U_6$ | $U_7$ | $U_8$ |
|---|---|---|---|---|---|---|---|---|---|
| | $U_1$ | | | | | | | | |
| | $U_2$ | | | | | | | | |
| | $U_3$ | | | | | | | | |
| | $U_4$ | | | | | | | | |
| | $U_5$ | | | | | | | | |
| | $U_6$ | | | | | | | | |
| | $U_7$ | | | | | | | | |
| | $U_8$ | | | | | | | | |

## Pairwise comparison between elements

**Table 7 - Pairwise comparisons between elements in $U_1$ under the criterion of $u_{11}$ .**

| Expert ( ) | $u_{11}$ | $u_{11}$ |
|---|---|---|
| | $u_{11}$ | |

**Table 8 - Pairwise comparisons between elements in $U_2$ under the criterion of $u_{11}$ .**

| Expert ( ) | $u_{11}$ | $u_{21}$ | $u_{22}$ | $u_{23}$ |
|---|---|---|---|---|
| | $u_{21}$ | | | |
| | $u_{22}$ | | | |
| | $u_{23}$ | | | |

**Table 9 - Pairwise comparisons between elements in $U_3$ under the criterion of $u_{11}$ .**

| Expert ( ) | $u_{11}$ | $u_{31}$ | $u_{32}$ |
|---|---|---|---|
| | $u_{31}$ | | |
| | $u_{32}$ | | |

**Table 10 - Pairwise comparisons between elements in $U_4$ under the criterion of $u_{11}$ .**

| Expert ( ) | $u_{11}$ | $u_{41}$ | $u_{42}$ | $u_{43}$ | $u_{44}$ |
|---|---|---|---|---|---|
| | $u_{41}$ | | | | |
| | $u_{42}$ | | | | |
| | $u_{43}$ | | | | |
| | $u_{44}$ | | | | |

**Table 11 - Pairwise comparisons between elements in $U_5$ under the criterion of $u_{11}$ .**

| Expert ( ) | $u_{11}$ | $u_{51}$ | $u_{52}$ | $u_{53}$ |
|---|---|---|---|---|
| | $u_{51}$ | | | |
| | $u_{52}$ | | | |
| | $u_{53}$ | | | |

**Table 12 - Pairwise comparisons between elements in $U_6$ under the criterion of $u_{11}$ .**

| Expert ( ) | $u_{11}$ | $u_{61}$ | $u_{62}$ |
|---|---|---|---|
| | $u_{61}$ | | |
| | $u_{62}$ | | |

**Table 13 - Pairwise comparisons between elements in $U_7$ under the criterion of $u_{11}$ .**

| Expert ( ) | $u_{11}$ | $u_{71}$ | $u_{72}$ | $u_{73}$ |
|---|---|---|---|---|
| | $u_{71}$ | | | |
| | $u_{72}$ | | | |
| | $u_{73}$ | | | |

**Table 14 - Pairwise comparisons between elements** in $U_8$ **under the criterion of** $u_{11}$ **.**

| Expert ( ) | $u_{11}$ | $u_{81}$ | $u_{82}$ |
|---|---|---|---|
| | $u_{81}$ | | |
| | $u_{82}$ | | |

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**Table 15 - Pairwise comparisons between elements in $U_8$ under the criterion of $u_{82}$ .**

| Expert ( ) | $u_{82}$ | $u_{81}$ | $u_{82}$ |
|---|---|---|---|
| | $u_{81}$ | | |
| | $u_{82}$ | | |