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INPRENUT APPLICATION IN DESIGN FOR ASSEMBLY: CASE STUDY ON WHEEL MOBILE ROBOT PLATFORM CONSTRUCTION

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ABSTRACT

Fasteners are a type of relationship which can have a significant impact on the assembly time of the system. Interference Press-fit Aluminum Nut (INPRENUT) is press-fit fastener designed to reduce pre-assembly setup time, pre-assembly setup time, disassembly time, reduce sharp object hazard and improve the quality of the product developed. Therefore, Design for Assembly (DFA) is one of the method used to study INPRENUT contribution in design efficiency improvement of the product assembly. Design efficiency manual fastener insertion in hollow tube follows Boothroyd and Dewhurst guidelines is analyzed and compared with the permanent rivet joint. A case study on wheel mobile robot platform construction is used to measure design efficiency of INPRENUT application in product assembly. The result shows the INPRENUT is able to simplified the design and reduce the part number in the assembly from 92 parts to 36 parts only. Design efficiency result comparison shows INPRENUT score is 7.46% whereas plastic bracket design of wheel mobile robot platform is 3.36%. This result give 222% of improvement. Furthermore, INPRENUT application shows wheel mobile robot parts assembly orientation is parallelled and easy to assembled.

Keywords: interference press-fit nut (INPRENUT), wheel mobile robot, design for assembly, design efficiency.

INTRODUCTION

Fastenings and joining is one type of non-permanent joints defined as an act of bringing together, connecting or uniting to become one or a unit and widely used in assemblies for their strength, reusability and appearance (Mackerle, 2003). Over the recent years, interference-fit joint technology methods have become important because interference-fit join contributes in a lot of engineering areas.

These tight joints give rigid contact to carry static as well as dynamic loads (Sogalad, Ashoka and Udupa, 2012). In view of Cao and Qin (2011), interference-fit assembly selection gives long service life, high reliability and low maintenance cost of the aerospace joint structure. The assembly must be thick-walled to tolerate the high pressure between the mated surfaces and this high pressure makes it hard to disassemble (Nystrom, Barlam and Klebanov, 2007).

The method that allow for easy to assemble and disassembly is the best method to be applied in student's design and build the project or mechanical construction model because of a few factors. The students are constrained with the time allocated and also need to work with the equipment and tools that will reduce the risk to harm them. This is the drawback if students project apply the permanent joint based on rivet. Figure-1(a) aluminum square tubes with burrs after cut using hack saw and Figure-1(b) shows an example in one of the project used aluminum squre tube and assembled with plastic bracket permanently with rivet.
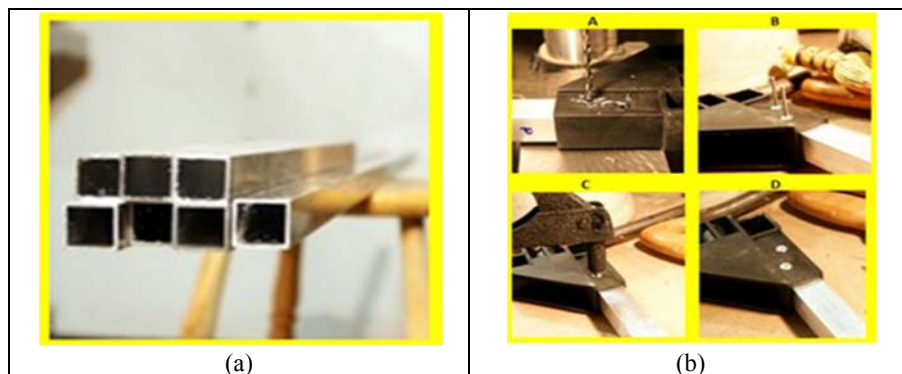

Figure-1. (a) Aluminum square hollow tube (b) Plastic bracket assembled with aluminium hollow square by using rivet.

In the concept design for efficiency there are two methods that need to be considered ahead of the rest that includes design for manufacturing (DFM) and design for assembly (DFA) (Todic *et al.*, 2012). Both methods are used by Todic *et al.* (2012) to assess the suitability of manufacturing capability without compromising the overall quality of functionality and usability of a product designed. From DFA, holistic quantitative analysis of design, materials, costing and manufacturing process can be obtained and performed for the next action for continuous improvement.

There are various procedures for quantitative assessment of the DFA but mainly focus on evaluating the design and quantitative improvements. Among the popular methods are; Lucas Design for Assembly Methodology, Hitachi Assemblability Evaluation Method and Boothroyd-Dewhurst Design for Assembly Method.

Barnes *et al.* (1997) using the Lucas DFA as a framework for developing computer-based DFA tool, which would support the development of CAD models and infer or extract relevant information. This approach will be able to develop systematically validation or evaluation procedures in generating an assembly sequence within the DFA analysis. Assemblability Evaluation Method (AEM) is developed with intention for a better assemblability of product by improving design of product (Todic *et al.*, 2012). DFA is able to improve the manufacturability of product to be assembled because of the contribution in

reengineering existing products and in supporting effective design and development of new products (Tatikonda, 1994).

This method provides a quantitative method based on analysis of product (Boothroyd *et al.*, 2002) and can be applied during preliminary design and detail design phases (Chiu and Okudan, 2010). The outcome from calculation design efficiency will be able to contribute to the design selection that can reduce costs and at the same time preserving or improving the quality of the product.

MANUAL ASSEMBLY OF INPRENUT

Joining non-permanent assembly from a group of single parts combined to serve certain purpose and forming part of a larger assembly is a good approach in technical education projects involving mechanical assemblies (reference). In Technical Vocational Education Training (TVET), there are mini project and final year project that requires mechanical assembly. Taking into account the difficulties faced to fabricate parts, parts accuracy, method of assembly and disassembly; the fastener innovation proposed named Interference Press-fit Nut (INPRENUT) is proposed as an alternative in assembly of the parts (Aznizam *et al*., 2015). The INPRENUT manufacturing and complete parts is shown in Figure-2(a) and Figure-2(b).

Figure-2. (a) INPRENUT fabrication using Didactic CNC Lathe (b) INPRENUT after fabrication.

This project objective is to provide a more effective way to construct the structure of the prototype platform. The method starts with the design of the mechanical fittings named INPRENUT to press-fit with aluminum tube. A few conceptual designs was introduced and reviewed. The results drive into introduction INPRENUT, a fastener fitted into aluminum hollow tube.

This will increase accuracy and precision of assembly because of both parts are concentricity. The approach will be able to reduce the time, weight, and

safety and increase flexibility in the platform construction by exploring the components and tools that minimize the cutting the parts with sharp tools.

An overview of design and fabrication of INPRENUT as discussed in Aznizam *et al*., (2015). The design started with understanding the needs from the problem faced and proposed solution based on affinity diagram, QFD and matrix design selection of the concept. Then, Mechanical CAD - CATIA is used to convert the initial idea for INPRENUT and hollow tube into a detailed

engineering design. INPRENUT assembly geometric models can be displayed graphically to visualize and able to be manipulated, analyzed and refined. Then, stress strength of INPRENUT assembly based on selected materials analyzed by ANSYS software for press-fit and pull-out. Once the Finite Element Analaysis (FEA) satisfy the requirements, the INPRENUT samples are fabricate. INPRENUT is made from aluminum materials and machined by using CNC lathe machine and conventional lathe machine as shown in Figure-2 (a) and Figure-2 (b).

There are three basic types of assembly systems which known as manual, special-purpose machine and programmable machine assembly (Boothroyd *et al.*, 2002).

In this case, the selection of assembly method is by manual assembly. This is because the target application of INPRENUT is for small-scaled project that involve mechanical assembly such as in a final year project (FYP), robotics competition at university, schools and Do-It-Yourself (DIY) gadgets.

Furthermore, workshop equipments in schools or in higher education institutions is still lacking. Therefore, most of the assembly process is still using manual method to assemble the parts. Therefore, the design efficiency measured based on the method proposed by Boothroyd

and Dewhurst (2002) is selected and long discussion about this is discussed in Boothroyd *et al*. (2002). The calculation for INPRENUT design efficiency is compared with the permanent rivet joint used as a benchmark.

DFA CASE STUDY: INPRENUT APPLICATION IN MECHANICAL CONSTRUCTION OF WHEEL MOBILE ROBOT PLATFORM

Application of INPRENUT in design for assembly
DFMA is utilized based on the information and general technical information to increase the design efficiency during assembly. The Boothroyd Dewhurst DFA method is applied to measure design efficiency of INPRENUT. An application of INPRENUT is presented in the replacement of parts for bracket wheel mobile robot platform construction. The design is presented in exploded view and generates Bill of Materials (BOM) from the Mechanical CAD (CATIA V5 R19) software.

The design efficiency is calculated and minimum parts count is review to improve the design. The construction of basic mechanical components plastic bracket wheel mobile robot platform is shown in Figure-3 (a) and exploded view is shown in Figure-3(b).
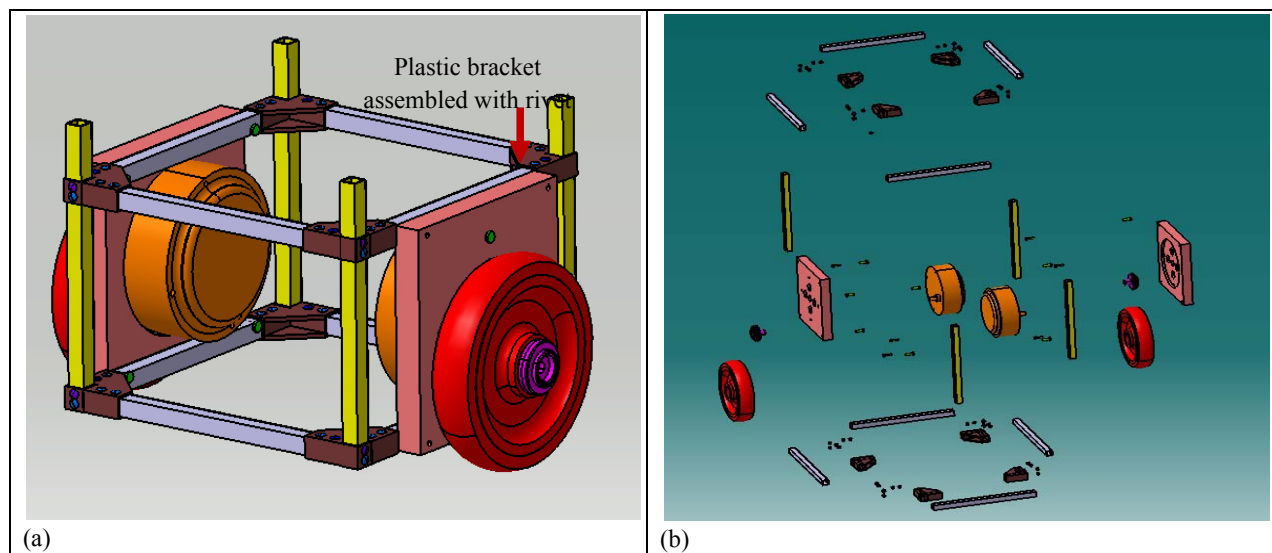

Figure-3. (a) Design of wheel mobile robot platform using plastic bracket. (b) Exploded view of wheel mobile robot parts (92 parts).

From Figure-3(b) also shows the composition of the parts is scattered, not parallel and with different orientation. The position and orientation of the components has contributed factor to reduce assembly time (Sturges, Hunt and Carnegie Mellon University, 1994).

For DFA investigation, Bills of Material (BOM) in robot platform component obtained from software is

summarized. It shows, the plastic bracket design of wheel mobile robot platform construction consists of nine various group of parts listed in Table-1 with ID NO from P01 until P09. From the data, total components used in the assembly can be counted. It shows, an assembly involves 92 parts altogether to develop the platform. The permanent joint using rivet used to assemble the plastic joint bracket

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and aluminum square hollow. In this assembly, total number of rivet used is 48 rivet parts.

The number of component in product assembly also one of the factors contributed to the total production time (Boothroyd and Dewhurst, 1986). For the purpose of improvement, an application of the design rules proposed by Boothroyd and Dewhurst (2002) for reducing the number of components in assembly is presented in Table-1.

Table-1. An Application of DFA rules for part reduction.

ID No.	Part name	Quantity	Decision	Justification
P01	Aluminum Square (12.7x12.7x200mm)	8	0	This part is replaced by aluminum round tube to simplify cutting and increase precision.
P02	Aluminum Bracket	8	0	This part is permanent joint. Require the approach that able to disassemble.
P03	Rivet part	48	0	This part is permanent joint. Require the approach that able to disassemble.
P04	Plastic bracket Design Pancake Motor Bracket	2	1	Basic standard component for the design function but with some modification. Add more holes to increase flexibility to locate the parts.
P05	Pancake 12V DC Motor	2	1	Basic standard component for the design function.
P06	Wheel	2	1	Basic standard component for the design function.
P07	Bush for wheel	2	1	Basic standard component for the design function.
P08	M4 screws	16	1	The screws is used to assemble the motor and INPRENUT.
P09	Aluminum Square (Pole)	4	0	This part is not include because the design changes.
Total number of part		**92**		From 92 parts, total number of rivet used is 48 units.

Notes: #1 indicates part required and #0 indicates a separate part is not required

From the analysis shown in Table-1, the new design ideally will comprise of five instead of nine various group of parts in original design. However, the aluminum square tube is proposed to be replaced with aluminum round tube with press-fit INPRENUT at both end of tubes.

Figure-4(a) shows new proposed assembly of WMR platform. An application of INPRENUT is presented in the replacement of rivet for plastic bracket wheel mobile robot platform construction. This two additional parts makes total various group of parts used in new design is seven. The alternative design also introduces the additional holes to the pancake motor bracket. These holes are able to increase flexibility of parts to be assembled at the bracket.

The position and orientation of the components has contributed factor to reduce assembly time (Sturges, Hunt and Carnegie Mellon University, 1994). From Figure 3(b), plastic bracket platform design shows the composition of the parts are scattered and with different orientation. However from Figure-4 (b), an exploded view of assembly shows the parts orientation is parallel in horizontal space environment.

This arrangement and parts used allow an adoption of Group Technology (GT) methodology; where the parts can be grouped together based on parts features, similarities and establish parameters for next action to reduce design time and effort. A summary of Various Group of parts and total number of parts involved in assembly is summarized in Table=2.

Table-2. Summary various group of parts and total number of parts used in new platform assembly.

ID No.	Part name	Quantity
P04	New Design Pancake Motor Bracket (add more holes)	2
N10	Aluminum Hollow 360	4
N11	INPRENUT	8
P05	Pancake 12V DC Motor	2
P07	Bush for wheel	2
P08	M4 screws	16
	Total parts	**36**

INPRENUT shows significant improvement in parts reduction number based on parts assembly and configuration shows Figure-4 and summary the various group of parts and total parts used in new platform assembly shows in Table-2.

The INPRENUT is able to simplified the design and reduce the part number in the assembly from 92 parts to 36 parts only. The elimination of rivet in assembly and replaced by screws provides non-permanent joint and easy to disassemble. Furthermore, INPRENUT can be reused back after dismantle from aluminum hollow tube by using dedicated pull-out tool.
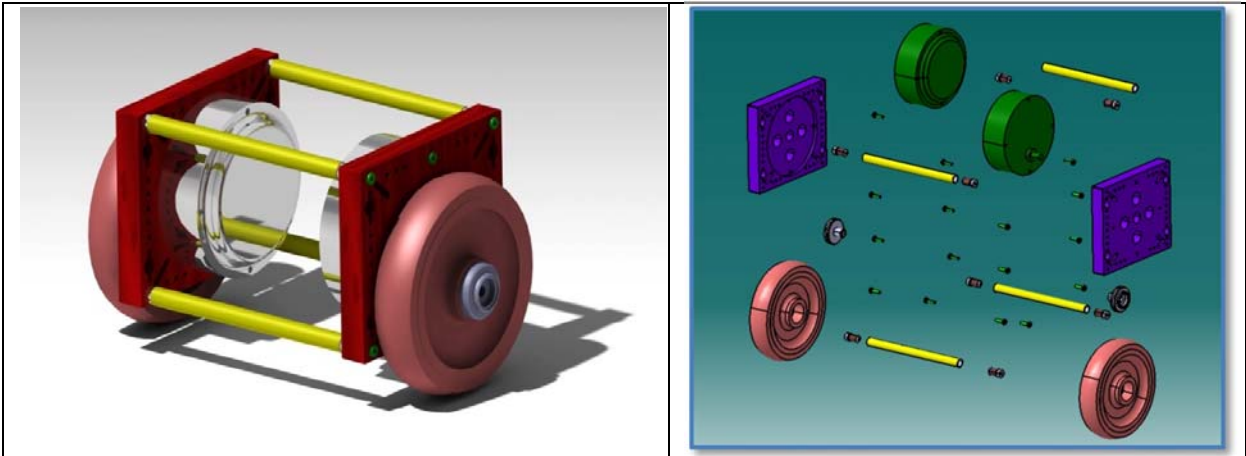

Figure-4. (a) New design of wheel mobile robot (b) New wheel mobile robot modified design for assembly exploded view (36 parts).

Design efficiency of platform with INPRENUT

The plastic bracket design wheel mobile robot is presented in exploded view and generates Bill of Materials (BOM) from the Mechanical CAD (CATIA V5 R19) software. From BOM, the total number of parts involve is identified.

The design efficiency is calculated and minimum parts count is review to improve the design. Design efficiency based on analysis of a product that compares the total assembly time for a product with the total assembly time for an ideal product determined. The efficiency can be used to compare various designs in terms of their relative efficiencies for manual assembly.

$$Design\ Efficiency = \frac{3N_M}{T_M} \tag{1}$$

N_M = Operation time

T_M = Estimate for theoretical minimum parts

Using a classification schemes and time and motion studies proposed by Boothroyd and Dewhurst (2002), the following two data bases for handling and insertion are established. The results of design efficiency proposed by Boothroyd (1991) of plastic bracket design and proposed new design are presented in Table-3 and Table-4.

Table-3. Design efficiency for plastic bracket wheel mobile robot design (Boothroyd (1991)).

Part No I.D no	Number of times the operation is carried out consecutively, RP	Tool Acquire Time, TA	Two-digit manual handling code	Manual handling time per part, TH	Two-digit manual insertion code	Manual insertion time per part, TI	Operation time, see TA + RP * (TH+TI)	Minimum Theorethical Part Count	Name of Assembly Wheel Mobile Robot Platform (OLD)
P01	8	-	01	1.43	00	1.5	23.44	0	Aluminum Square (12.7x12.7x200mm)
P02	8	-	30	1.95	00	1.5	27.6	0	Aluminum Bracket
P03	48	7.3	11	1.8	30	2.6	218.5	0	Rivet
P04	2	-	00	1.13	30	3.6	9.46	1	Old Design Pancake Motor Brakcet
P05	2	-	30	1.95	22	7	17.9	1	Pancake 12V DC Motor
P06	2	-	30	1.95	03	5.2	14.3	1	Wheel
P07	2	-	30	1.95	00	1.5	6.9	1	Bush for wheel
P08	16	2.9	11	1.8	31	5.3	116.5	1	M4 screws
P09	4	-	01	1.43	00	1.5	11.72	0	Aluminum Square (Pole)
DESIGN EFFICENCY = 3Nm/Tm							446.32	5	
DESIGN EFFICIENCY		**=**	**0.0336**		**or**	**3.36%**	**Tm**	**Nm**	

Table-4. Result of DFA for the New Wheel Mobile Robot Design (Boothroyd, (1991).

Part No I.D no	Number of times the operation is carried out consecutively, RP	Tool Acquire Time, TA	Two-digit manual handling code	Manual handling time per part, TH	Two-digit manual insertion code	Manual insertion time per part, TI	Operation time, see TA + RP * (TH+TI)	Minimum Theorethical Part Count	Name of Assembly Wheel Mobile Robot Platform (NEW)
P04	2	-	00	1.13	30	3.6	9.46	1	Old Design Pancake Motor Brakcet
P05	2	-	30	1.95	22	7	17.9	1	Pancake 12V DC Motor
P06	2	-	30	1.95	03	5.2	14.3	1	Wheel
P07	2	-	30	1.95	00	1.5	6.9	1	Bush for wheel
P08	16	2.9	11	1.8	31	5.3	116.5	0	M4 screws
N10	4	-	00	1.13	31	5.3	25.72	1	Aluminum hollow tube
N11	8	7.3	11	1.8	30	3.6	50.5	1	INPREANUT
DESIGN EFFICIENCY = 3Nm/Tm							241.28	6	
DESIGN EFFICIENCY		**=**	**0.0746**		**or**	**7.46%**	**Tm**	**Nm**	

From Table-3, the design efficiency obtained from plastic bracket design is only 3.36%. Further investigation on arrangement and calculation of result new design efficiency is presented in Table-4.

Design efficiency result comparison shows new design score is 7.46% whereas plastic bracket design of wheel mobile robot platform is only 3.36%. This result is viewed as not sufficient as many companies accepted the product design efficiency should be around 20% to 30% (Boothroyd and Dewhurst, 1989). This is because the numbers of parts use to replace the other parts removing increase back the number of components and this increase the total of assembly time. However, from the result it shows the design efficiency is increase up to 222% of the initial one.

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IMPLEMENTATION

An implementation of the INPRENUT assembly can be shown in the development of wheel mobile robot platform as shown in Figure-5. It learned that the during platform construction, the students is able to modified the sizes of the platform if required, accuracy of parts fabrication is increased, parts orientation simplify an assembly and simplify the parts fabrication.
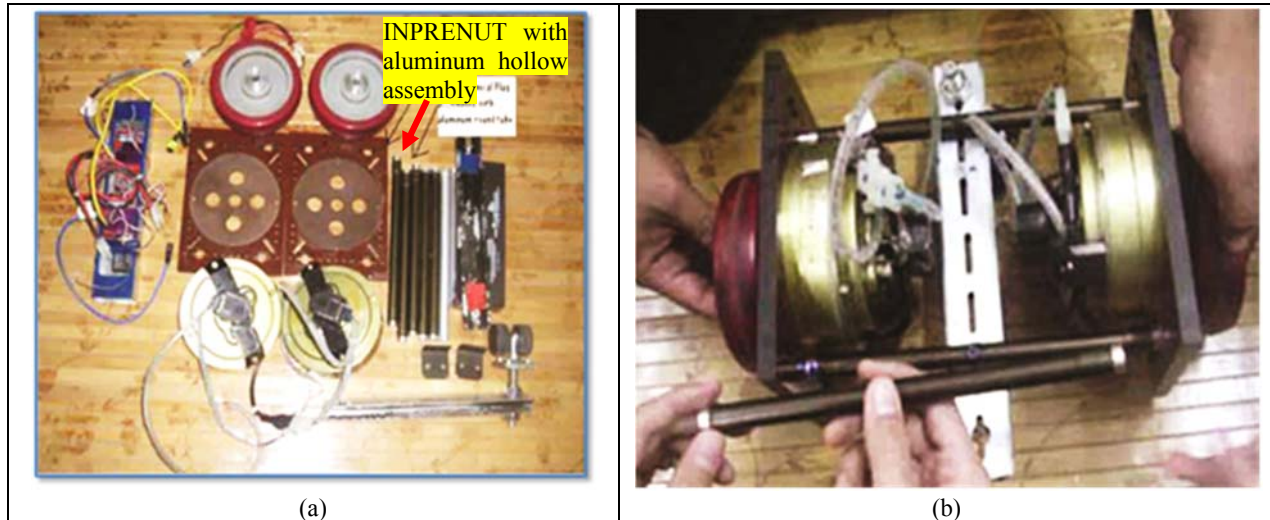

(a)   (b)

Figure-5. (a) Components used in wheel mobile robot assembly (b) An assembly of wheel mobile robot platform.

CONCLUSIONS

The INPRENUT is designed to reduce time and cost of manual part assembly. Plastic bracket assemble with pop-up rivet is used as benchmark in the design for assembly study. From Bills of Material (BOM), the total parts using plastic bracket with pop-up rivet is 92 components. However, with an application of INPRENUT the parts number reduced until 36 parts. The elimination of pop-up rivet in assembly and replaced by screws provides non-permanent joint and easy to disassemble. This result shows the design efficiency of wheel mobile robot platform assembly is improved from 3.36% to 7.46% or 222% improvement from initial one based on case study presented. Furthermore, parts orientation using INPRENUT is parallel and unscattered. This type of assembly also able to disassembly easily because non permanent fastener is applied in the assembly. Future improvement to increase potential application of INPRENUT in students project, DIY or hobbiest project, multi-dimensional INPRENUT need to be designed and tested.

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