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Design of Swarm Robotics Using Klann Mechanism

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Abstract

Swarm robotics concept is inspired from small insects such as ant or bee colonies. It composes a system consisting of many small robots with simple control mechanisms capable of achieving complex collective behaviors on the swarm level such as aggregation, pattern formation, and collective transportation. The most remarkable characteristic of swarm robots are the ability to work cooperatively to achieve the common goal. Thus swarm robotics is a new approach to the coordination of multi-robot system which consist large number of simple robots which takes it inspiration from social insects. It is an interesting alternative to classical approaches to robotics because of some properties of problem solving present in the social insects, which is flexible, robust, decentralized and self-organized. This work gives overview of swarm robotics concept and its application in material handling. Computational swarm intelligence is modelled on the social behavior of animals and its principle application as an optimization technique. Swarm robotics is relatively new and rapidly developing field which draws an inspiration from swarm intelligence

Keywords*- Klann Mechanism, Swarm Robotics, Linkages, Sensor, Wi-Fi Bot*

I. INTRODUCTION

Nature has always inspired researchers. Swarm robotics is a branch of multi-robot systems that embrace the ideas of biological swarms such as insect colonies, flocks of birds and schools of fish. The term "**s**warm" is used to refer "a large group of locally interacting individuals with common goals". Swarm robotics systems as well as their biological counterparts consist of many individuals exhibiting simple behaviors. While executing these simple behaviors, individuals are capable of producing complex collective behaviors on the swarm level that no individual is able to achieve alone. We are applying this swarm intelligence to a robot which has Klann mechanism.

II. LITERATURE REVIEW

[1]Aleksis Liekna, Janis Grundspenkis "Towards practical application of swarm robotics: overview of swarm tasks" by Aleksis Liekna and Janis Grundspenkis represent the description of use of swarm robots in industrial applications.

[2]Aleksandar Jevti´c, Diego Andina "Swarm Intelligence and Its Applications in Swarm Robotics" by AleksandarJevti´cdescribes about computational swarm intelligence and the behavior of animal and their principle application is an optimization technique Optimal Design of Klann's based walking Mechanism for Water-running Robots represent information mainly about Robot running on Klann's Mechanism with help of links and gear transmission.

[3] U. Vanitha, V. Premalatha "Mechanical Spider Using Klann Mechanism" SR is currently one of the most important application areas of SI. Swarms provide the possibility of enhanced task performance, high reliability (fault tolerance), low unit complexity and decreased cost over traditional robotic systems. They can accomplish some tasks that would be impossible for a single robot to achieve.

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[4] Urvil P Patel “Design and Finite Element Analysis of Mechanical Spider” Swarm robotics (SR) refers to the application of swarm intelligence techniques to the analysis of activities in which the agents are physical robotic devicesth at can effect changes in their environments based on intelligent decision-making from various input. The goal of this approach is to study the design of robots(both their physical body and their controlling behaviors)such that a desired collective behavior emerges from the inter-robot interactions and the interactions of the robots with the environment, inspired but not limited by the emergent behavior observed in social insects.

[**5] Ying Tan, Zhong-yang Zheng** “Research Advance in Swarm Robotics”, describes the relation of swarm with nature and nature’s aspects with comparison between single robot & multi-individual system, Also research on its algorithm, including cooperative control mechanisms, navigating and searching applications.

[6] Miss. Suman Sharma. “Mechanical Spider by victimization Klann Mechanism”, describes the ineffective of wheels on rough and rocky areas, and advantage of Klann mechanism to climb stairs and step over curbs, or travel areas that are not accessible with wheels. The paper briefly describes its helpfulness in venturesome material handling, clearing minefields, or securing a neighborhood that is in danger.

[7] R.Arjunraj, A. Arunkumar, R. Kalaiyasaran, B. Gokul, R. Elango “Fabrication of Six-Legged Kinematic Moving Mechanism”, describes the kinematics of the movement for a six-legged mobile, inspired from the living world, as well as the command and control system.

III.KLANN MECHANISM

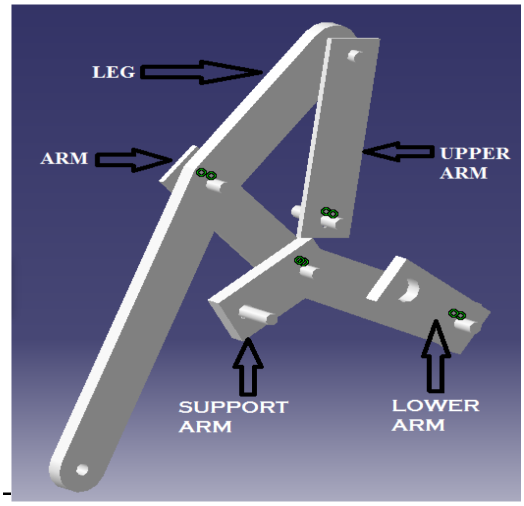

Fig.1 Klann Mechanism

The main objective of our project is to replace the function of wheel in order to overcome the difficulty of travelling in uneven terrain. In this mechanism links are connected by pivot joints and convert the rotating motion of the crank into the movement of foot similar to that of animal walking. The proportions of each of the links in the mechanism are defined to optimize the linearity of the foot for one-half of the rotation of the crank. The remaining rotation of the crank allows the foot to be raised to a predetermined height before returning to the starting position and repeating the cycle. Two of these linkages coupled together at the crank and one-half cycle out of phase with each other will allow the frame of a vehicle to travel parallel to the ground. It has been a hobby for a number of years to develop a bicycle without wheels that could walk. It would move on legs and resemble a large insect. A linkage was developed that satisfied the design criteria and several small-scale prototypes were built that demonstrated the concept. Applications for the linkage go beyond human-powered machines. The links are connected by pivot joints and convert the rotating motion of the crank into the

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movement of a foot similar to that of an animal walking. Two of these legs coupled together at the crank can act as a wheel replacement and provide vehicles with a greater ability to handle obstacles and travel across uneven terrain while providing a smooth even ride. Initially it was called the Spider Bike but the applications for this linkage have expanded well beyond the initial design purpose of a human-powered walking machine. This linkage could be utilized almost anywhere a wheel is employed from small wind-up toys to large vehicles capable of transporting people. The relationships for the linkage have been established and are covered by several patents. The simplicity and scalability of the walking device, along with a little imaginative engineering, lead to numerous possibilities. The Klann linkage is a planar mechanism designed to simulate the gait of legged animal and function as a wheel replacement.

Working of Klann Mechanism

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The Klann linkage is a planar mechanism designed to simulate the gait of legged animal and function as a wheel replacement. The linkage consists of the frame, a crank, two grounded rockers, and two couplers all connected by pivot joints. The proportions of each of the links in the mechanism are defined to optimize the linearity of the foot for one-half of the rotation of the crank. The remaining rotation of the crank allows the foot to be raised to a predetermined height before returning to the starting position and repeating the cycle. Two of these linkages coupled together at the crank and one-half cycle out of phase with each other will allow the frame of a vehicle to travel parallel to the ground. The Klann linkage provides many of the benefits of more advanced walking vehicles without some of their limitations. It can step over curbs, climb stairs, or travel into an area that are currently not accessible with wheels but does not require microprocessor control or multitudes of actuator mechanisms. It fits into the technological space between these walking devices and axle-driven wheels. The foot of a walking mechanism is the part of the mechanism that comes in direct contact with the ground as indicated. As the crank turns, the foot traces out a cyclical path relative to the body of the walker; this path is known as the locus. A crank based leg system with the foot, locus, and crank labeled. The direction of movement of the linkage to the crank and the foot through the locus are indicated. Additionally, a fixed point in the linkage relative to the body of the walker is indicated with a black square. The locus can be divided into four parts: the support, lift, return, and lower phases. Throughout the support phase, the foot is ideally in contact with the ground. During the lift the foot is moving toward its maximum height in the locus. During the return, the foot reaches its maximum height off the ground and moves in the same direction as the body of the walker. Finally, during the lower the foot descends in height until it makes contact with the ground.

Advantages of Klann mechanism

1. Klann Mechanism makes legged mobility easier.
2. It directly converts a rotation into a gait.
3. Easy to build.
4. Initial cost is reasonably low.
5. Construction expense is low.
6. Heavy load can be carried.
7. It can be run in rough surfaces.
8. Easy to control.

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IV. ACTUAL CONCEPT OF SWARM ROBOTICS

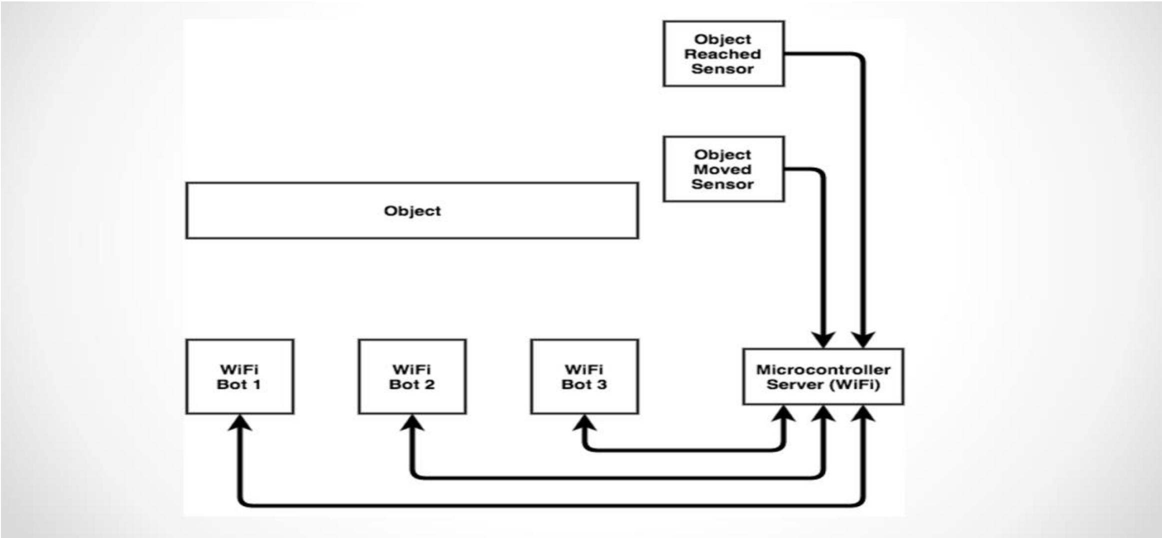

Fig. 2 Concept

All bots are connected with each other by means of a Wi-Fi module which is connected to every bot. The bots are controlled by the Server (Microcontroller) by means of Wi-Fi. All bots are placed serially. An ultrasonic sensor is placed on the first bot (i.e. Wi-Fi bot 1) as well as on the initial destination (i.e. object moved sensor) and final destination (i.e. object reached sensor). An object with particular weight is placed in front the Wi-Fi bots and parallel to initial destination. As the first bot is connected with an ultrasonic sensor, the sensor will keep on detecting any object in front of it. Once we keep a object in front of the sensor, it will detect an obstruction in its range and the sever will command the bot to move in forward direction by means of wi-fi. Once the bot 1 comes in contact with the object it will try to push it forward. If it is successful in pushing the object, it will keep on pushing the object up till its final destination. If not it, the ultrasonic sensor at initial destination will wait for 8 sec and will give signal to the server for next command. Once the sever gets signal from the ultrasonic sensor it will command the bot 2 to move forward. The bot 2 will come in contact with the object and both bots (i.e. bot 1 and 2) will try to push it forward to its final destination. If not the ultrasonic sensor at initial condition will wait for another 8 sec and will give the server a signal for its next command. After that the 3rd bot will be instructed to move forward and all together (i.e. all bots) will try to push the object to its final destination. Once the object reaches to its final destination. The ultrasonic sensor at final destination will detect the presence of the object and will command the server to instruct all the bots to return back to its final destination.

Degree of Freedom (DOF) for klann mechanism

The Degree of freedom (DOF) of a mechanical system is the number of independent parameters that define its configuration. It is the number of parameters that determine the state of a physical system and is important to the analysis of systems of bodies in mechanical engineering, aeronautical engineering, robotics, and structural engineering.

The Klann mechanism uses six links per leg, whereas the Jansen's linkage developed by Theo Jansen uses eight links per leg, with one degree of freedom. It can walk only on even surfaces and terrain.

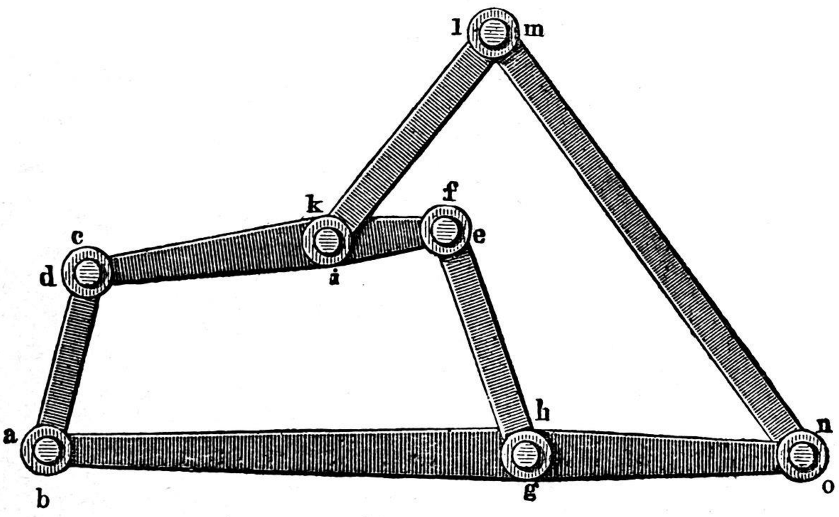

Fig. 3 Klann Linkage [2]

Where,
n = Degree of Freedom (DOF)
l = Number of links = 6
j = Number of joints = 6
Kutzbatch's criterion Equation,
n = 3 (l-1)- 2j
…. This equation is called kutzbatch criterion equation.
n = 3(6-1)- 2×6
= 15-12
n = 3
Degree of Freedom (DOF) = 3

V. DESIGN CALCULATIONS

Calculation of gear and pinion:

Motor Specification:
Voltage (V) = 12 V
Current (I)= 1 Amp
Power (P) = Voltage (V) × Current (I)
= 12 × 1 = 12 W

(1) Take 10 rpm for 1st iteration,

$$P = \frac{2\pi NT}{60}$$

$$12 = \frac{2\pi \times 10 \times T}{60}$$

T= 11.4591N-m

(2) Take 20 rpm for 2nd iteration

$$12 = \frac{2\pi \times 20 \times T}{60}$$

T = 5.7295 N-m

(3) Take 30 rpm for 3rd iteration

$$12 = \frac{2\pi \times 30 \times T}{60}$$

T = 3.8197 N-m

The 3rd iteration torque value is satisfied for our design weight and capacity. So taking T = 3.8197 N-m and 30 rpm.
Input speed = 30 rpm
Output speed = 10 rpm … (Assume)

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Gear ratio (G) =Reduction ratio (i)

$i = \frac{Inputspeed}{OutputSpeed}$

$= \frac{30}{10}$

$\boldsymbol{i = 3}$

Gear ratio = 3

$i = \sqrt{i}$

$= \sqrt{3}$

$i = 1.7320$

$i_1 = 0.8\ [i^2 \frac{k1}{k2}]^{1/3}$

Gear and pinion are same material, i.e. acrylic (PMMA),

So, k1 = k2

$$i_1 = 0.8[3^2]^{1/3}$$
$$i_1 = 2.667$$

For better design, assume 20^0 full depth system, for that minimum number of teeth of Pinion is,

$z_{min} = \frac{2}{sin^2\ \alpha}$

$= \frac{2}{sin^2\ 20}$

$= 17.097$

$z_{min} = 18$

Where,

$i_1 = \frac{Z_G}{Z_P}$

$2.667 = \frac{Z_G}{18}$

$Z_G = 48.006$

Table no. 6.1 Gear & Pinion Teeth relation

18	48.006
17	45.339
16	42.672
15	40.005
14	37.338
13	34.671
12	32.004

In this table find the gear and pinion teeth, so we are assuming

$$Z_P = 12$$
$$Z_G = 32$$

Gear Ratio (G) = $\frac{32}{12}$

G = 2.667

$G = \frac{Z_G}{Z_P} = \frac{N_P}{N_G}$

$\frac{32}{12} = \frac{30}{N_G}$

$\mathbf{N_G = 11.25}\ \boldsymbol{Rpm}$**(Output speed)**

Gear Ratio (G) = $\frac{\text{Input Speed}}{\text{Onput Speed}} = \frac{N_P}{N_G}$

$= \frac{30}{11.25}$

G = 2.667

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Pitch Circle Diameter(PCD):
Diameter of pinion (small spur gear)
Diameter of pinion (d_P) = Pitch Circle Diameter(PCD)
(d_P) = (PCD) =m × Z_P
= 2 ×12
(d_P) = (PCD) = 24 mm

Diameter of Gear (Big spur gear)
(d_g) = (PCD) = m × Z_P
= 2 ×32
(d_g) = (PCD) = 64 mm

Input speed = 30rpm
T= T_{design}= 3.8197 N-m
d_p= 25 mm = 0.025 m

Tangential Load (P_f):
T =$\frac{P_f \times d_p}{2}$
3.8197 =$\frac{P_f \times 0.025}{2}$
$\boldsymbol{P_f}$ **= 305.576 N**

Effective Load (P_{eff}):
$P_{eff} = \frac{P_f \times C_S}{C_V}$
$P_{eff} = \frac{458.32 \times 1.5}{C_V}$
$\boldsymbol{P_{eff}}$ **= 458.364N**
Where, $C_V$is neglected because rpm is very low.

Beam strength
$S_b = m.b.\sigma_b.y$
Where, b= 10module =10m
Now, the gear and pinion material are same the acrylic (PMMA) of ultimate tensile strength are same so,
(S_{ut}) = 79.6 N/mm^2
(S_{yt}) = 86 N/mm^2
$\sigma_b = \frac{S_{ut}}{3}$
=$\frac{79.6}{3}$
$\boldsymbol{\sigma_b}$ **= 26.5333 N/$\boldsymbol{mm^2}$**

Lewies's strength equation,
Y = 0.484 - $\frac{2.87}{Z_P}$
Y = 0.2448
Now,
S_b =26.5333 $\times 10m \times m \times 02448$
S_b =66.0148 m^2N

Module (m):
S_b = FOS× P_{eff}
66.0148m^2= 1×458.364
m = 2.43

m ≅ 2
Factor of safety (FOS)
S_b = FOS× P_{eff}
S_b = 66.0148× m^2
$\mathbf{S_b = 264.059}$ **N**

S_b = FOS× P_{eff}
264.059 = FOS× 458.36
FOS = 0.576
FOS ≅ 1
Hence, FOS is 1 our design is safe.
Calculation of shaft:
Motor Specification:
Speed = 30 rpm
Power = 12watt
Voltage = 12v
Torque, T = 3.8197× 10^3 N.mm
The motor shaft is made of mild steel and allowable shear stress of mild steel for shaft is 42mpa … (Standard value from V.B. Bhandari)
$T = \frac{\pi d^3}{16} \times \tau_s$
$3.8197\times 10^3 = \frac{\pi d^3}{16} \times 42$
$d^3 = 463.180$
d = 7.7371 mm
d ≅ 8mm
….. (The diameter of shaft is 8mm is taken from table in V.B. Bhandari, table no. 9.1 page no. 331)
Calculation of bots:
Application requirement: In our application the bot should move the object of 1 kg from one place to another place.

1. Normal Bot (2no's)
Speed = 30 rpm
Voltage = 12 V
Current (I) = 1 Amp
Power (P) = 12 Watt
Torque (T) = 3.8197 N-m
Diameter of Wheel = 65mm = 0.065m
Radius of wheel = $\frac{65}{2}$=32.5mm = 0.0325m
Weight = 1.2 Kg … (Calculate on weight machine)
Convert in newton,
W = 1.2 ×9.81
W= 11.772 N
Mass (m) = $\frac{W}{g}$… (g = 9.81 m/sec^2)
$m = \frac{11.772}{9.81}$
m = 1.2kg
Now calculating velocity,
$V = \frac{\pi DN}{60}$
$= \frac{\pi \times 0.065\times 30}{60}$
V = 0.1021 m/sec
Now calculating Acceleration (a),
Acceleration velocity with respect to time

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Acceleration (a) = $\frac{\text{Velocity}}{\text{Time}} = \frac{V}{t}$

Time calculating for 1 revolution per minute (rpm) i.e. 60sec

$a = \frac{V}{t} = \frac{0.1021}{60}$

Acceleration (a) = 0.00170 m/sec^2

Force = Mass×Acceleration

F = m × a

= 1.2 × 0.00170

F = 2.04 × 10^$^{-3}$ N

Torque = Force × Radius

T = F ×r

= 2.04×10^$^{-3}$× (32.5× 10^{-3})

T = 6.63 × 10^$^{-5}$ N-m

Add without weight torque= 3.8197N-m

T = 6.63 × 10^$^{-5}$+ 3.8197

T = 3.8197 N-m

By converting

1 N-m = 0.102 Kg-m

Capacity of Normal Bot = Torque × 0.102

= 3.8197× 0.102

= 0.3896 Kg-m

Capacity of Normal Bot = 390 g-m

2. Klann Mechanism Bot (1 nos.)

Weight = 2 Kg calculate on weight machine

Mean Diameter of Gear = 50.66mm = 0.05066m

Radius of Gear = $\frac{0.05066}{2}$= 0.02533m

Convert in newton,

W = 2 ×9.81

W= 19.62 N

Mass (m) = $\frac{W}{g}$… (g = 9.81 m/sec^2)

m =$\frac{11.772}{9.81}$

m = 2kg

Now calculating velocity,

$V = \frac{\pi DN}{60}$

$= \frac{\pi \times 0.05066 \times 30}{60}$

V = 0.0795 m/sec

Now calculating Acceleration (a),

Acceleration velocity with respect to time

Acceleration (a) = $\frac{\text{Velocity}}{\text{Time}} = \frac{V}{t}$

Time calculating for 1 revolution per minute (rpm) i.e. 60 sec

$a = \frac{V}{t} = \frac{0.0795}{60}$

Acceleration (a) = 0.001325 m/sec^2

Force = Mass× Acceleration

F = m × a

= 2 × 0.001325

F = 2.65 × 10^$^{-3}$ N

Torque = Force × Radius

T = F ×r

= 2.65 × 10^$^{-3}$× (0.02566)

$T = 6.799 \times 10^{-5}$ N-m
Now,
Add without weight torque = 3.8197N-m
$T = 3.8197 + 6.799 \times 10^{-5}$
T = 3.8197N-m
1 N-m = 0.102 Kg-m
Capacity of Klann Mechanism Bot = Torque × 0.102
= 3.8197× 0.102
= 0.389 Kg-m
Capacity of Klann Bot = 390 g-m
Total Capacity of All Bots = Klann Mechanism Bot + (2× Normal Bot)
= 390 + (2*390)
Total Capacity of All Bots = 1170g-m

VI. MATERIAL

The Klann Mechanism uses Acrylic as a material. Acrylic is a plastic manufactured using one or more derivatives of acrylic acid. Polymethyl Methacrylate acrylic, or PMMA, is one of the more widely used forms of acrylic due to its exceptional weatherability, strength, clarity and versatility. Transparent, translucent opaque and colored polymers are available with varying levels of heat resistance, light transmissions, impact strength, flow rates and release capabilities. PMMA acrylic sheet exhibits glass-like qualities – clarity, brilliance, transparency, translucence – at half the weight with up to 10 times the impact resistance. It can be tinted or colored, mirrored or made opaque. A number of coatings can be applied to a sheet or finished part for performance enhancing characteristics such as scratch resistance, anti-fogging, glare reduction and solar reflectivity.

VII. ASSEMBLY IN A CATIA MODELLING

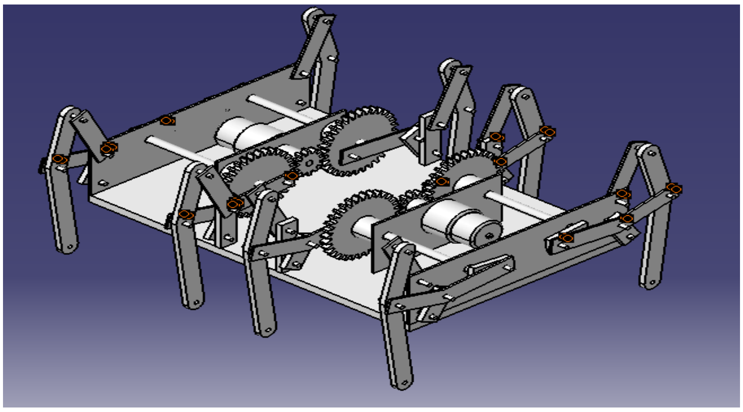

Fig. 4 Assembly of Klann Robot

VIII. ADVANTAGES, LIMITATIONS AND FUTURE SCOPE

A. Advantages:

1. Some advantages of swarm-robotic systems make them more appealing then classical robotics.
2. Some tasks may be too complex for a single robot to perform.
3. The solution speed is increased when using large number of robots, even when the cooperation is not present.
4. It is easier to design simple robot units required for a swarm.
5. The communication between the robots is reduced because of the indirect interactions.
6. SR is currently one of the most important application areas of SI.
7. Swarms provide the possibility of enhanced task performance, high reliability (fault tolerance), low unit complexity and decreased cost over traditional robotic systems.

8. They can accomplish some tasks that would be impossible for a single robot to achieve.
9. Research in the field of SR shows that a set of relatively primitive individual behaviors enhanced with communication will produce a large set of complex swarm behaviors.

B. Limitations:

1. Failure may occur due to insufficient power supply
2. Programming is required to perform tasks.
3. Slipping of wheels may occur on rough surface.

IX. FUTURE SCOPE

1. Robot swarms might one day tunnel through rubble to find survivors, monitor the environment and remove contaminants, assist dwindling bee populations in pollinating crops, and self-assemble to form support structures in collapsed buildings.
2. Swarms of robots acting together to carry out jobs could provide new opportunities for humans to harness the power of machines.
3. They could play a part in military, or search and rescue operations, acting together in areas where it would be too dangerous or impractical for humans to go.
4. In industry too, robot swarms could be put to use, improving manufacturing processes and workplace safety.
5. Researchers are developing Artificial Intelligence to control robots in a variety of ways. The key is to work out what is the minimum amount of information needed by the robot to accomplish its task.

X. CONCLUSION

This work has given the detailed overview of current swarm intelligence research and its applications in swarm robotics. Swarm robotics is an interesting alternative to classical approaches to robotics because of some properties of problem solving by social insects, which is flexible, robust, decentralized and self-organized. Advantages of swarm-based robotics are numerous. Some tasks may be too complex for a single robot to perform. The speed is increased when using several robots and it is easier to design a robot due to its simplicity. Rapid progress of hardware brings innovations in robot design allowing further minimization. The communication between robots is reduced, because of the interactions through the environment. We are reaching a stage in technology where it is no longer possible to use traditional, centralized, hierarchical command and control techniques to deal with systems that have thousands or even millions of dynamically changing, communicating, and heterogeneous entities. The type of solution swarm robotics offers, and swarm intelligence in general, is the only way of moving forward when it comes to control of complex distributed systems. The most forceful motivation for studying legged robots is to give access to places that are inaccessible or too dangerous for human beings. Legged robots can be used for rescue work after earthquakes and in hazardous places such as the inside of a nuclear reactor, giving biologically inspired autonomous legged robot's great potential. Thus, in our paper we have proposed a method to replace the function of wheel in order to overcome the difficulty of travelling in uneven terrain. The most important benefit of this mechanism is that, it does not require microprocessor control or large amount of actuator mechanisms.

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