1. INTRODUCTION

The conflicts between nations has taken a shift from an open confrontation involving conventional defense forces, to a low intensity and indirect attacks, targeting civilian population creating unrest and colossal damages, that can strangle economic developments and pose a great security concern.

The effort to counter the threats from adversaries is of great concern for a developing nation like India. The conventional strategies to defeat, involves considerable manpower, resources, effort and time. To be more successful, it is wiser to gather information about adversary’s strategies that would strength our armed forces for counter action. This has been the concern of many nations. World over many countries have focused their R&D towards meeting this goal.

A viable solution that would address the issue is the development of autonomous systems. An autonomous system would be a boon for armed forces both at peace time and at combat time to gather information that would otherwise be difficult to reveal the adversaries strategies. A battle outcome is decisive based on availability of information about the adversary’s strategies. This goes by the following “He who fires first wins the battle” an old saying. “He who knows the adversary’s strategies wins the battle” - information age.

Configuration of an autonomous system to meet the armed forces requirements is a technological challenge and is the primary focus for any R&D. In isolation many technologies have emerged that may find a potential application in the autonomous system for armed forces. The areas include perception system, artificial muscles, smart materials, 3D trajectory estimation, control, guidance and actuation etc. The presentation primarily focuses on the few selected technology available, the technology to be developed, issues in integrating the technology.

2. AUTONOMOUS SYSTEM

The primary function of the autonomous system is to move to the area of interest and gather valuable information about adversary’s movements and strategies. The application could be for detoxification, neutralization of contaminated areas, Areas affected by nuclear radiation, logistic supports, counter measures etc. Both land based system and air based system are potential for the application. Such a system should be capable of the following functions.

a. The 3D information about the surrounding are gathered using multiple sensors operating at different spectrum and different zones. These are registered with respect to the vehicle coordinate for sensor data fusion to generate the 3D profile of the surrounding.

b. From the gather detailed 3D information the terrain profile, obstacles location, classification of safe and unsafe zones and identification of traversable path taking into consideration the vehicle dimension and dynamics.

c. The vehicle should negotiate the traversable path safely.

d. If a path is defined, by way points, the vehicle has to update it’s position and it’s attitude continuously, and move close to the given way points and track the path close to the actual path. This is done by path planning.

e. Is a path is not defined the vehicle has to identify obstacles take the safe path and identify. This process is called as path finding.

2.1 For military application the following are desirable for autonomous system

i. All terrain mobility through non conventional locomotion preferably electronically controlled.

ii. Silent and stealthy operations.

iii. Blending with the surrounding (Altering shape, colour and rigidity).

iv. Perpetual power for Self surviving capabilities.

v. Deploy and forget.

vi. Self destruction on detection.

vii. Rugged System.

2.2 The Military application can be Classified into

i. Logistics application – Land based

ii. Surveillance - Arial and land based

iii. Counter measures – Land & Arial based
3. **AUTONOMOUS NAVIGATION**

An Autonomous system, when fielded will sense the environment, avoid obstacles and identify safe path for navigation, a control, guidance and actuation unit to manipulate the vehicle to execute assigned task safely and stealthily, without human assistance. Autonomous navigation process involves sense plan and act. Fig. 1 shows the various components of a autonomous navigation system.

![Autonomous Navigation Diagram](image)

**Figure 1. Autonomous Navigation.**

3.1 **Perception System**

Perception system is one that senses the environment, creates a 3D projection of environment and detects obstacle and identifies traversable path through which the vehicle can move. The perception system can be group into two categories as active and passive. Vision Based systems are passive, Time of flight system are active.

3.2 **Localization**

Vehicle localization refers to knowledge of vehicle’s position and attitude in given global reference frame. Every time the vehicle moves it updates it’s position and attitude.

3.3 **Path Planning**

Moving through preplanned paths, the autonomous navigation system does a path planning. With no preplanned path, the autonomous navigation system does path finding using reactive navigation.

3.4 **Vehicle control**

The vehicle system should have the drive by wire features. The vehicle should be configured to be for electronic control of speed, steering, braking and changing direction.

3.5 **Communication system**

This will be to upload command and mission data to the vehicle and download surveillance data from the vehicle, which includes video, image and other pertinent information.

4. **DARPA GRAND CHALLENGE AND RESULTS**

**2004 Event** : 150 miles in 10 hours Only CMU red team could complete only 7.36 miles.

**2005 Event** : Five vehicle completed the course.

1. Stanley Stanford Racing Team Stanford University, Palo Alto, California 6:54 First place
2. Sandstorm Red Team Carnegie Mellon University, Pittsburgh, Pennsylvania 7:05 Second place
3. Highlander Red Team Too 7:14 Third place
4. Kat-5 Team Gray The Gray Insurance Company, Metairie, Louisiana 7:30 Fourth place
5. TerraMax Team TerraMax Oshkosh Truck Corporation, Oshkosh, Wisconsin 12:51 Over 10 hour limit, fifth place

**2007 event** : Urban challenge, a 60 mile course urban course, to be completed in less than 6 hours. Rules included obeying all traffic regulations while negotiating with other traffic and obstacles and merging into traffic.

1. Tartan Racing 19 Boss 2007 Chevy Tahoe Carnegie Mellon University, Pittsburgh, Pennsylvania 4:10:20 1st Place; averaged approximately 14 mph (22.53 km/h) throughout the course.
2. Stanford Racing 03 Junior 2006 Volkswagen Passat Wagon Stanford University, Palo Alto, California 4:29:28 2nd Place; averaged about 13.7 mph (22.05 km/h) throughout the course[6]
3. VictorTango 32 Odin 2005 Ford Hybrid Escape Virginia Tech, Blacksburg, Virginia 4:36:38 3rd Place; averaged slightly less than 13 mph (20.92 km/h) throughout the course[4]
4. MIT 79 Talos Land Rover LR3 MIT, Cambridge, Massachusetts Approx. 6 hours 4th Place.
5. The Ben Franklin Racing Team 74 Little Ben 2006 Toyota Prius University of Pennsylvania, Lehigh University, Philadelphia, Pennsylvania No official time.

5. **TECHNOLOGICAL DEVELOPMENTS**

5.1 **Passive Perception system**

A perception system is one that senses the environment, creates a 3D projection of environment and detects obstacle and identifies traversable path through which the vehicle can move. The perception system can be group into two categories based on the principle of operation 1. Vision Based system 2. Time of flight system. Stereo vision system and optical flow method are the two vision based technique on which 3D information will be extracted.

5.2 **Stereo Vision**

This “State of the art technology” used in DARPA Grand Challenge & MARS ROVER program. It is a two identical cameras system.

A single camera cannot give the depth information. Minimum two cameras are required. The cameras should be identical. As shown in Fig 1. The objects A, B, C will be projected on camera 1 as shown. But the projection of the objects A, B, C will get shifted depending on the position and distance. The distance from the position with reference projection in camera 1 to the projection in camera 2 is called disparity. From the disparity the depth information can be estimated. f1 f2 are the focal length of the cameras. For identical cameras f1 = f2. 2T represent the baseline, the distance between the centers of the two cameras.
5.2.1 Matching point

The principle behind the stereo image processing is to identify matching points from camera 1 image to matching points in camera 2 images. The search is made simple by meeting the epi-polar constraint. By meeting the epi-polar constraint the search for the matching will be confined to a single line.

In order to meet the epi-polar constraint the two cameras need to perfectly oriented (image planes are coplanar) and synchronized. However, such thing is never possible in the real world because of physical difference in mounting and orienting. The epi-polar constraint can boosting the matching points.

5.2.1 Epi Polar Plane

Epipolar geometry is a consequence of the coplanarity of the camera centres and scene point. The camera centres, corresponding points and scene point lie in a single plane, known as the epipolar plane.

The steps involved to get the images to meet the epipolar constraint.
1. Camera calibration.
2. Image warping.

5.2.1 Camera Calibration

The checker board in figure is used for camera calibration. The checker board is pictured in the camera in different orientation to get the camera matrix. Camera Calibration involves extraction of the following parameters, Focal length, camera centers, camera orientation and translation one camera with reference to the second camera.

Image warping is carried out on the images to orient one image with respect to the other image so that search for matching points lie in a line.

5.2.1 Disparity map generation

This involves pixel to pixel correspondence. For each pixel in the left image, search for the most similar pixel in the right image.

The identification of pixel matching results in the disparity map which is shown in Fig. 12. The relation ship between range and the base line, focal length and the disparity is given in Fig. 11 gives the range information.

5.3 Active Perception System (Time of flight based).

Ladar, Radar and ultrasonic system uses the time of flight concept.

5.3.1 Principle of LADAR

- Laser pulse is emitted by Laser Transmitter
- Reflected pulse from target is detected by Laser Receiver
- Time interval ($\Delta T$) between emission of laser pulse and its detection measured by a precision counter

Range = (C x $\Delta T$)/2
C-Velocity of light

6. Localization System

A vehicle moves from point ‘a’ passing through points b, c, and d to reach point e. Point ‘a’ is the reference for the vehicle and updates it’s position and attitude as it moves through the points to reach point e.

The following sensors are used to get the position information and attitude information.

a. Global positioning system.
b. Altitude Heading Reference System (Magnetic compass, Accelerometer, gyros).
c. Odometer (Wheel encoder).

The position information is basically updated using GPS data. In the absence of GPS data (dead reckoning), the data from the AHRS and the odometer are combined to estimate the position of the vehicle as it moves.
8. OBSTACLE AVOIDANCE

Obstacle avoidance is based on reactive navigation and it does the task of path finding. In Reactive Navigation the obstacles position with respect to direction of movement of the vehicle is estimated to maneuver the vehicle to avoid the obstacles. The possible obstacle as shown as star symbol could be a positive obstacle, negative obstacle, non traversable gradient both positive and negative in the direction of the vehicle.

9. PATH FINDING AND VEHICLE CONTROL (LOCAL PATH PLANNING)

The obstacle avoidance is done by controlling the steering angle and manipulating the speed and brake. In Figs. 11 & 12 the arrow indicates the vehicles path as it avoids obstacles.

10. WAY POINTS, PATH PLANNING AND VEHICLE CONTROL (GLOBAL PATH PLANNING)

The waypoints a, b, c are to be touch as the vehicle moves. The shortest path would be a straight line joining a and b. Most of the time the vehicle’s attitude may not be in the same direction. Hence the vehicle has to steer continuously or in discrete steps to reach point b. On
reaching point b, the attitude of the vehicle may not be in the direction of point c. Hence by steering way point c will be touched. The precise controlling of the vehicle and traversing through the way points taking into consideration the vehicle dimension and dynamics and accurately updating the vehicle position is a very challenging task. Success and failure in autonomous navigation is mostly attributed to this factor. This was clearly demonstrated in the Darpa grand challenge 2005.

In the start all waypoint are classified as attractive. On occasion when the waypoint is not approachable due to presence of obstacles, such waypoints will be automatically classified as repulsive and avoided. The vehicle will then home on to the next attractive way points.

11. VEHICLE CONTROL SYSTEM

i. Drive by wire speed control
ii. Drive by wire steering control
iii. Automatic gear selector
iv. Drive by wire Brake control
v. Drive by wire direction control
vi. Sensors for feedback for all drive by wire actuators and for other vehicle parameters.

12. COMMUNICATION SYSTEM

a. Video data from the vehicle to base station.
b. Vehicle position in global coordinate
c. Command data and way points from base station
d. Emergency stop and activation of self destruction form base station.

13. POTENTIAL TECHNOLOGY

a. Electroactive polymers
   i. Artificial muscle
b. Non electroactive polymers
   i. Conductive and Photonic Polymers
   ii. Smart Structures and Materials
   iii. Deformable Polymers
   iv. Chemically Activated
   v. Shape Memory Polymers
   vi. Inflatable Structures
   vii. Light Activated Polymers
   viii. Magnetically Activated Polymers

14. ELECTROACTIVE POLYMERS (ARTIFICIAL MUSCLE)

Electro-active polymers (or EAPs) are polymeric materials whose shapes are modified when a voltage is applied to them. They can be used as actuators or sensors. As actuators, they are characterized by the fact that they can undergo a large amount of deformation while sustaining large forces. Due to the similarities with biological tissues in terms of achievable stress and force, they are often called artificial muscles, and have the potential for application in the field of robotics, where large linear movement is often needed. When certain types of electro-active polymers are physically flexed, they produce a voltage output. This effect allows EAPs to be used as potential sensors in various types of equipment. With EAPs’ inherent flexible and durable nature, long sensor life is expected.

EAPs such as ionic polymer metal composites (IPMCs) are active materials that exhibit interesting bidirectional electromechanical coupling phenomena, e.g., by bending
an IPMC strip, a voltage output is obtained, while a voltage input is able to cause the strip to bend. Thus, they are also large motion sensors. The output voltage can be calibrated for a standard-size sensor and correlated to the applied loads or stresses. EAPs can be manufactured and cut in any size and shape.

Electro-active ceramic actuators (for example, piezoelectric and electrostrictive) are effective, compact actuation materials, and they are used to replace electromagnetic motors. However, while these materials are capable of delivering large forces, they produce a relatively small displacement, on the order of magnitude of a fraction of a percent. Since the beginning of the 1990s, new electro-active polymer (EAP) materials have emerged that exhibit large strains, and they have led to a great paradigm change with regards to their capability. The unique properties of these materials are highly attractive for bio-mimetic applications such as biologically inspired intelligent robots. Increasingly, engineers are able to develop EAP actuated mechanisms that were previously imaginable only in science fiction. Electric motors tend to be too weak, while hydraulics and pneumatics are too heavy for use in robotics or prosthetics. EAPs, in comparison, are lightweight, quiet and capable of energy densities similar to biological muscles.

In ionic EAPs, actuation is caused by the displacement of ions inside the polymer. Only a few volts are needed for actuation, but the ionic flow implies a higher electrical power needed for actuation, and energy is needed to keep the actuator at a given position.

- Most conventional mechanisms are driven by actuators requiring gears, bearings, and other complex components.
- Emulating biological muscles can enable various novel manipulation capabilities that are impossible today.
- Electroactive polymers (EAP) are emerging with capability that can mimic muscles to actuate biologically inspired mechanisms.
- EAP are resilient, fracture tolerant, noiseless actuators that can be made miniature, low mass, inexpensive and consume low power.
- EAP can potentially be used to construct 3-D systems, application for robotics, which can be imagined today as science fiction, but a reality in near future.

15. ELECTRONIC EAP
(i) Dielectric EAP
(ii) Ferro Electric EAP
(iii) Graft Elastomer

16. IONIC EAP
(i) Conductive Polymers
(ii) IPMC (Ionic Polymer Metal Composites)
(iii) Electro Rheological Fluids (ERF)
(iv) Ionic gel
(v) Carbon nano tubes

17. SMART MATERIALS

17.1 Chromism
A process that induces a reversible change in the colours of compounds. This is based on a change in the electron states of molecules, especially the pi or d electron state, this phenomenon is induced by various external stimuli which can alter the electron density of substance.

Chromism is classified by the kind of stimuli as
i. Thermochromism – Heat
ii. Photohromism – Light
iii. Electrochromism – redox active sites, metal ions or organic radicals
iv. Solvachromism – Polarity of solvent

Chromic phenomena are those in which colour is produced when light interacts in variety of ways
i. Reversible colour change
ii. The absorption and reflection of light
iii. The absorption of energy followed by emission of light

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<tr>
<th>EAP type</th>
<th>Advantage</th>
<th>Disadvantage</th>
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<tr>
<td>Electronic EAP</td>
<td>Can operate in room conditions for a long time</td>
<td>Requires high voltages (~150V/?m)</td>
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<td>Rapid response (mSec levels)</td>
<td>Requires compromise between strain and stress</td>
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<td></td>
<td>Can hold strain under DC activation</td>
<td>inadequate for low temperature</td>
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<td></td>
<td>Induces relatively large actuation forces</td>
<td>Glass transition temperature is</td>
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<td></td>
<td>actuation tasks</td>
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<tr>
<td>Ionic EAP</td>
<td>Large bending displacements</td>
<td>Except for CPs, ionic EAPs do not</td>
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<td></td>
<td>Provides mostly bending actuation (longitudinal mechanisms can be constructed)</td>
<td>hold strain under DC voltage</td>
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<td>Requires low voltage</td>
<td>Slow response (fraction of a second)</td>
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<td>Bending EAPs induce a relatively</td>
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iv. The absorption of light and energy transfer
v. The manipulation of light

17.2 PH sensitive polymers

Though Non Electrical mechanically activated polymers and non electro active polymers can also be used in robots as sensors, actuators, for camouflaging, it is the Electro active polymers, that is of primary interest for robotics application of non conventional locomotion.

18. EMERGING SCENARIO

Attempts have been made to design and develop legged robots. The Boston dynamic group in the USA has developed a robot called the big dog.

19. CONCLUSION

All terrain mobility through non conventional locomotion using electrical energy, Silent and stealthy operation, blending with the surrounding (Altering shape, colour and rigidity), Perpetual power for Self surviving capabilities, Deploy and forget, Self destruction on detection, the features of desirable autonomous system for armed force application in the battle field is no more a written document, but a reality in the near future. The Development in the field of electroactive polymers, smart materials and the integration of such materials for robotic application will be a challenge for R&D.

REFERENCES

15. http://www.sop.inria.fr/robotvis/personnel/zzhang/CalibEnv/CalibEnv.html (demo)