Development of *Smart Cane*

An affordable knee-above obstacle detection and warning system for the visually impaired

Project Funded by

wellcome trust

(Affordable Health Care in India – Translation Award)

PHOENIX

भारतीय प्रौद्योगिकी संस्थान दिल्ली
INDIAN INSTITUTE OF TECHNOLOGY DELHI

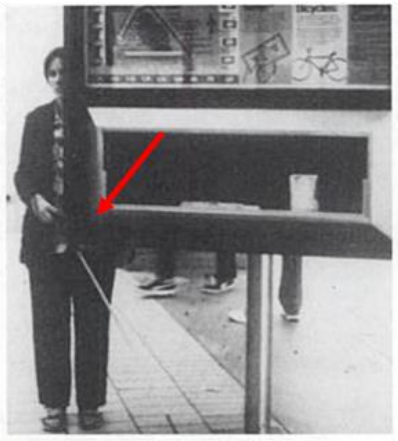
SAKSHAM
~~dis~~ability

RSG Meeting

Indian Institute of Technology Delhi

January 31, 2012

Limitations of the White Cane



Restricted range and inability to detect knee-above obstacles causes unexpected collisions and upper-body injuries.

Study of Commercially Available ETAs

- Procurement and study of commercially available ETAs.
- User testing with 5 users each, one week usage.
- Evaluation of key technical parameters.
- Capturing best features and avoiding mistakes

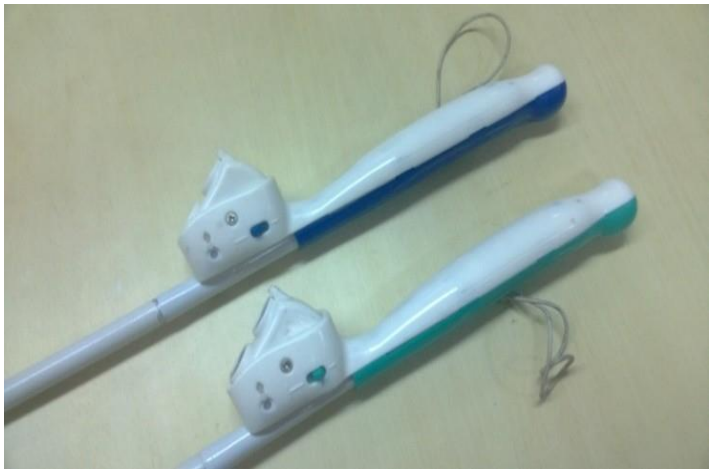
Lessons Learnt from Study of ETAs

- ETAs which replace white cane for mobility conceal some valuable information about texture.
- Users do not like feedback about presence of obstacles in the form of tactile vibrations in head.
- User prefer ETAs where only one hand is used. Further ETAs which are not flexible in gripping styles or force users to adopt to new gripping styles may not work.
- ETAs which provide feedback as auditory output via earphone conceal some valuable auditory clues from the environment which is necessary and important for mobility, path planning and safety.
- Success of an ETA not only depends on technology but on complete eco-system involving ease of learning, ease of usage, training, portability, appearance etc.
- User prefer devices which are small in size and weight but do not prefer rigorous scanning to detect obstacles.

Smart Cane

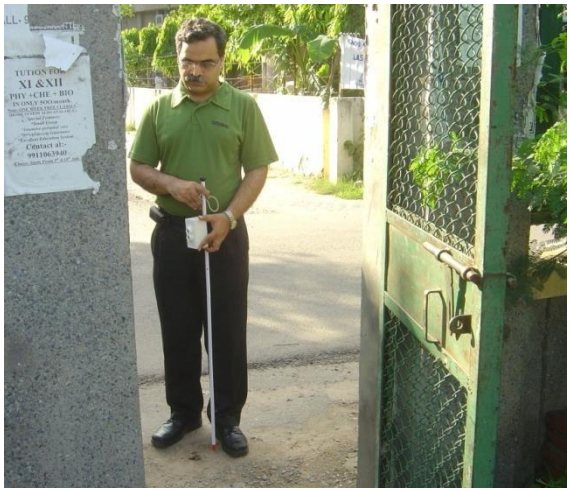
- Smart Cane is an obstacle detection and warning system
- Compliments the functionality of white cane.
- Can be easily mounted and detached from white cane.
- Detects obstacles with the use of ultrasonic waves.
- Presence of obstacles is conveyed by easily perceptible and intuitive vibratory patterns.

Current Status



Various Navigation Scenarios

Path Finding



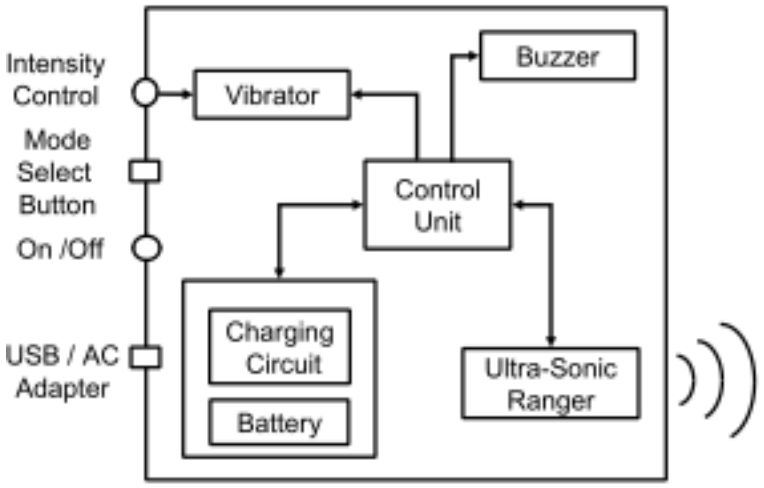
Gate Detection

Indoor Navigation

Raised obstacle detected 3m away

Smart Cane Characteristics

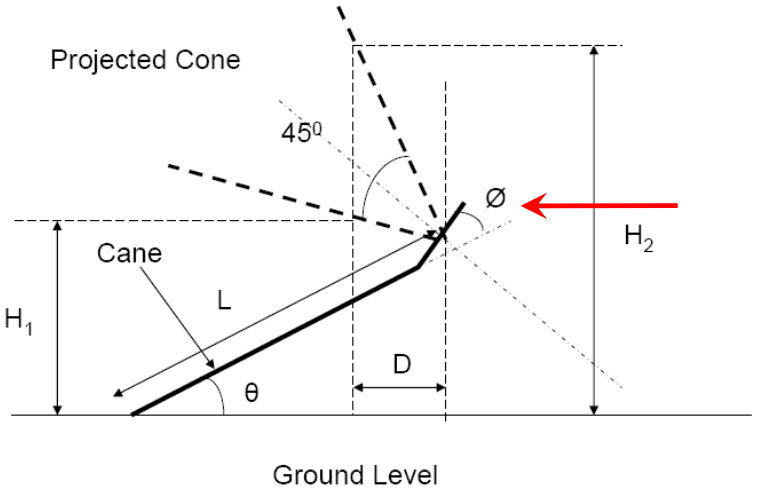
- Optimized ranging algorithm (50 Hz).
- Rechargeable Li –ion battery.
- Indoor and outdoor modes of navigation.
- User adjustable sensor angle
- Accommodating wide varying grips
- Affordable



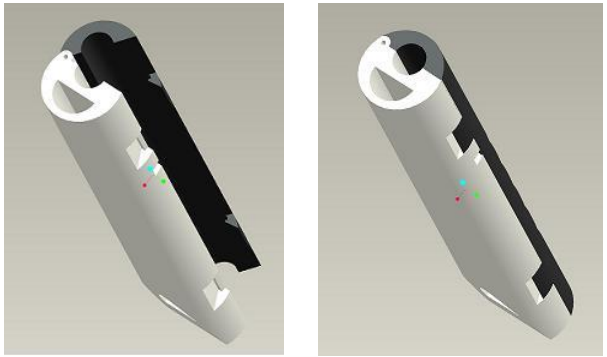
Flexibility




Device usage with widely varying grips.

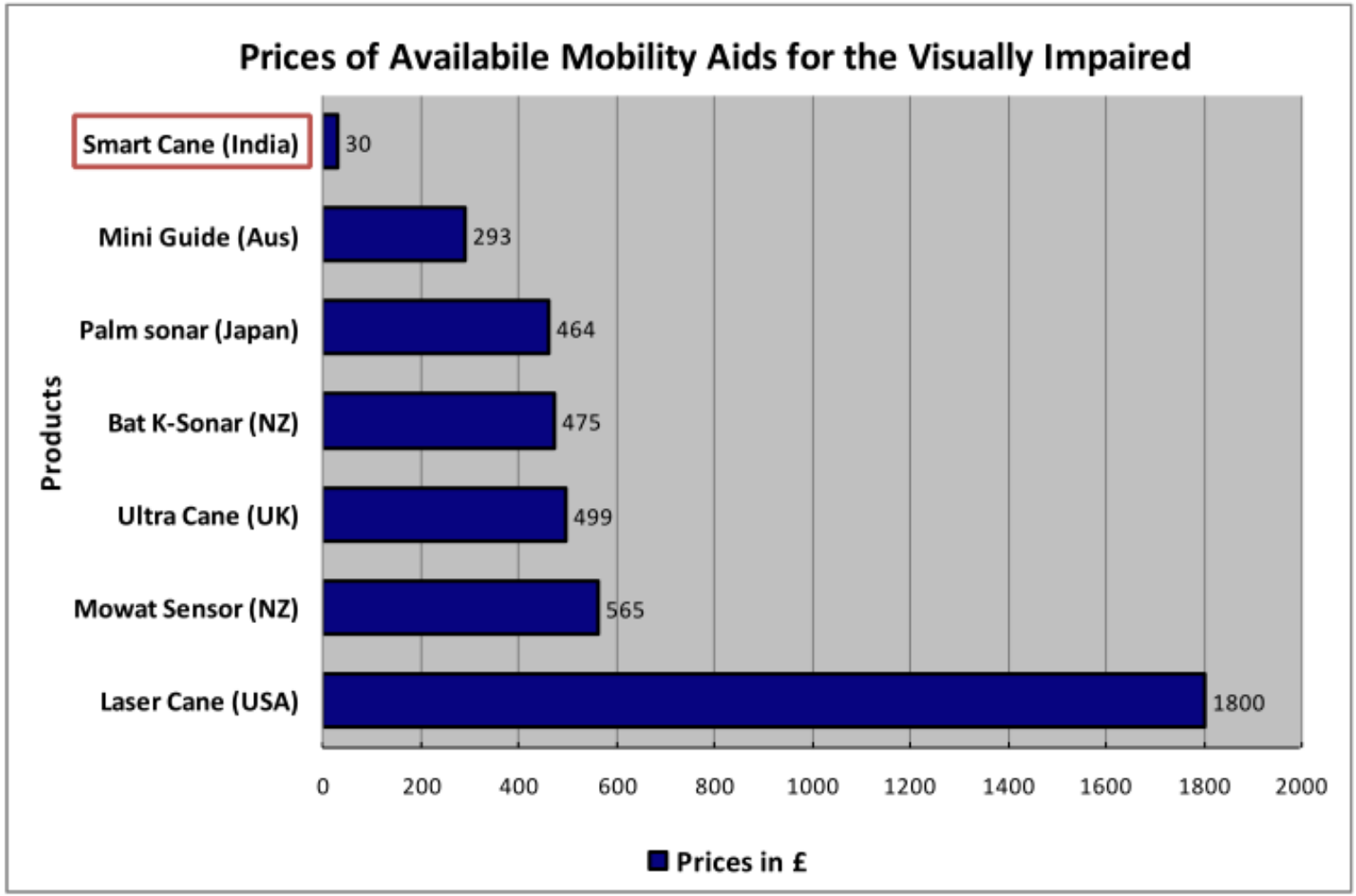


User adjustable sensor angle.



Cane-mountable through an attachment mechanism.

Affordability



Device Evolution and Next Steps





2005	Inception
2006	Proof of Concept
2007	Lab Prototype
	Indian Patent
2008-09	Design Improvements
	Limited Control Trials
2008-10	Joint Development
June 2010	Presentation at WT
June 2011	Funding Agreement
July 2011	Funds Release

Four Milestones

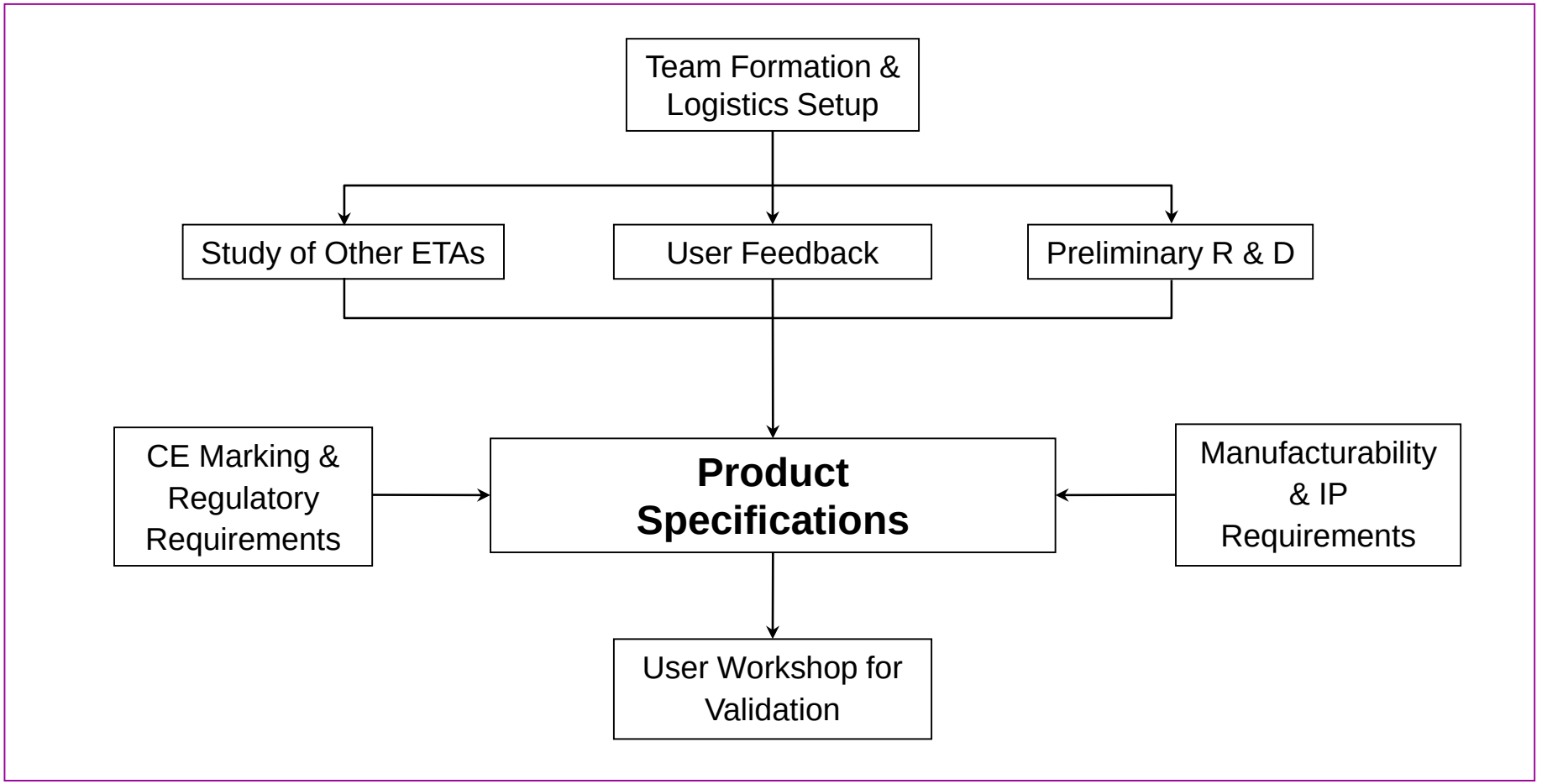
Project Initiation & Specification Refinement

R & D and Development of Field Deployable Product

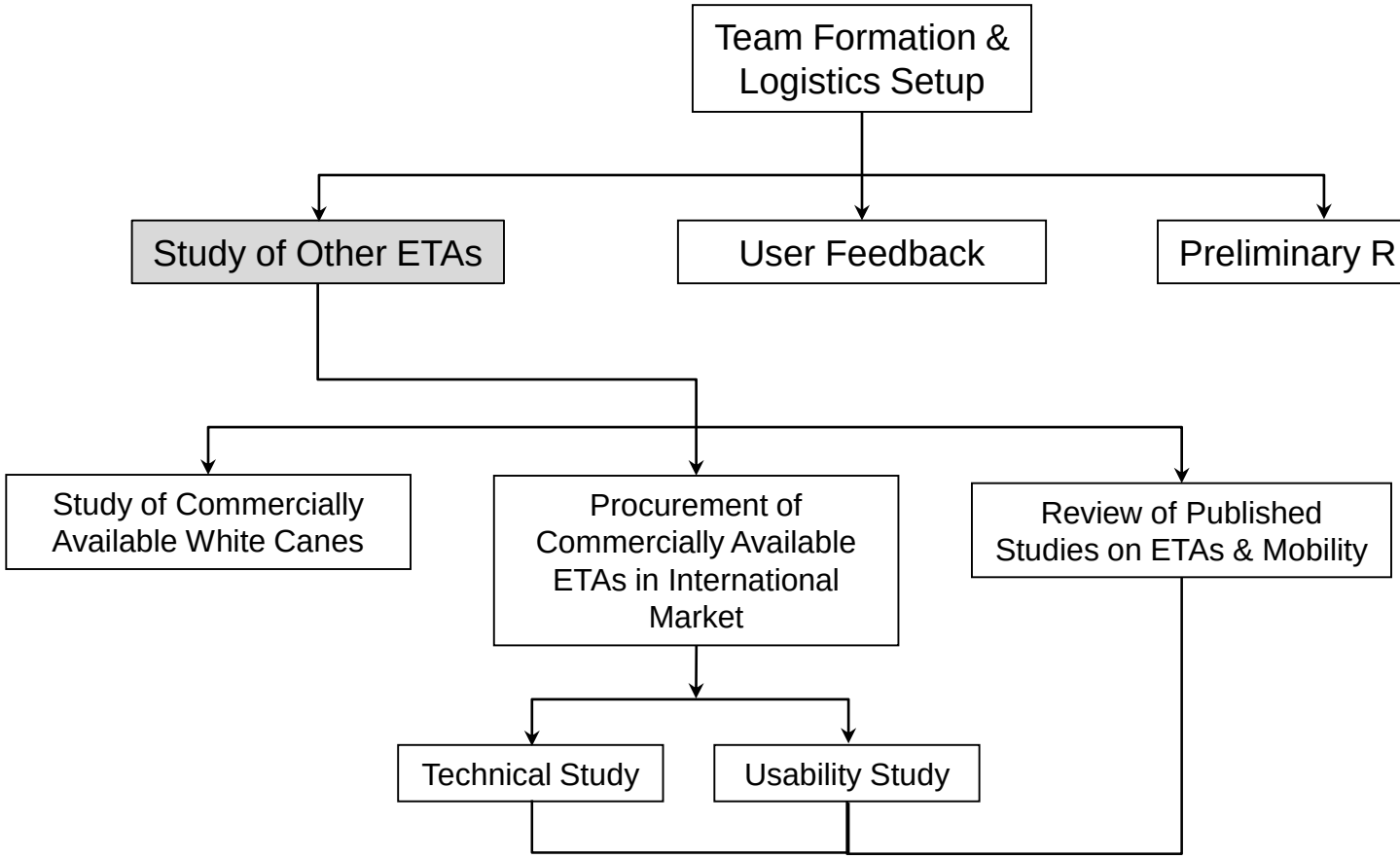
Product Testing & Field Trials

Product Refinement & Approvals

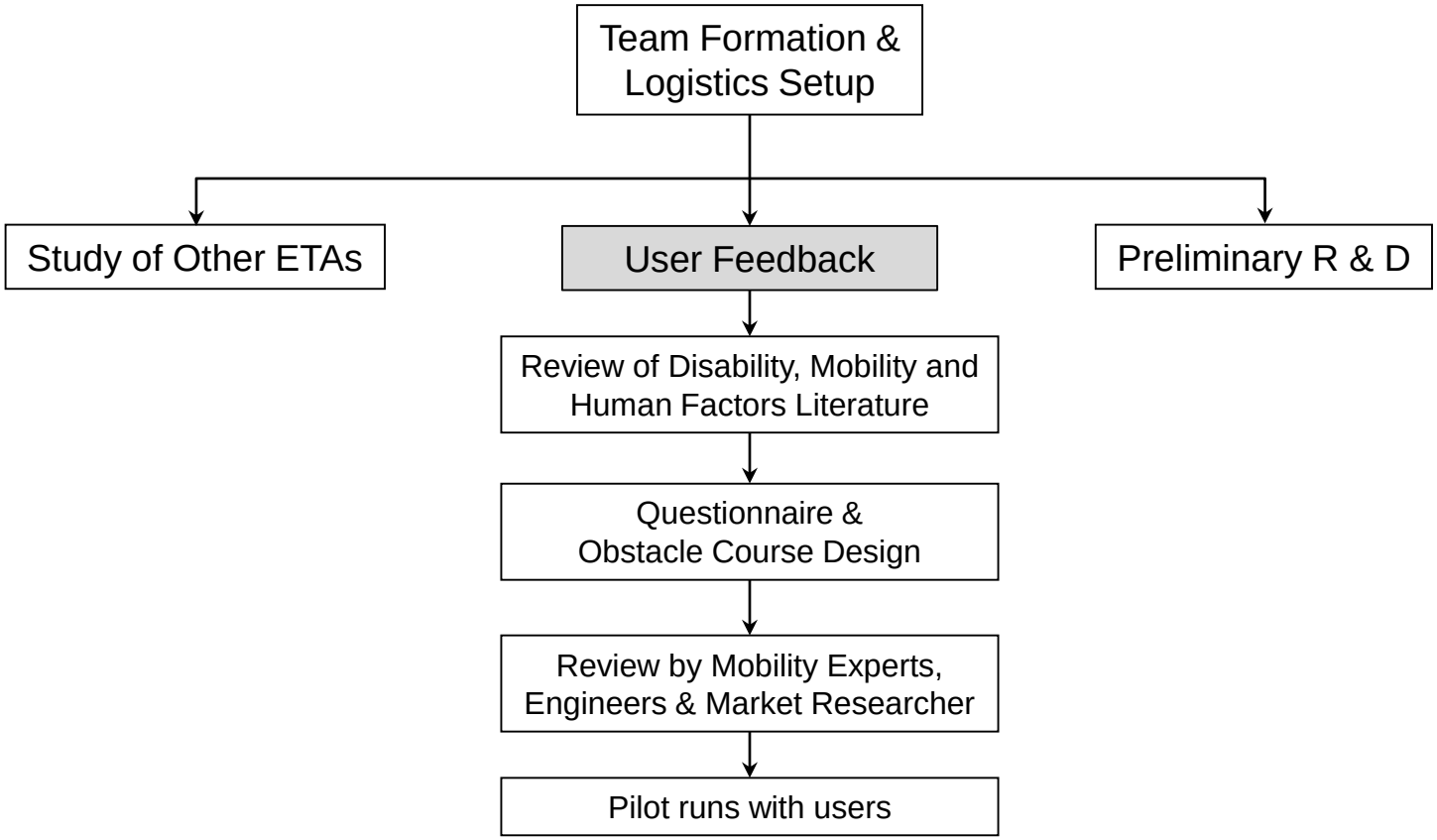
Milestone 1: Key Activities



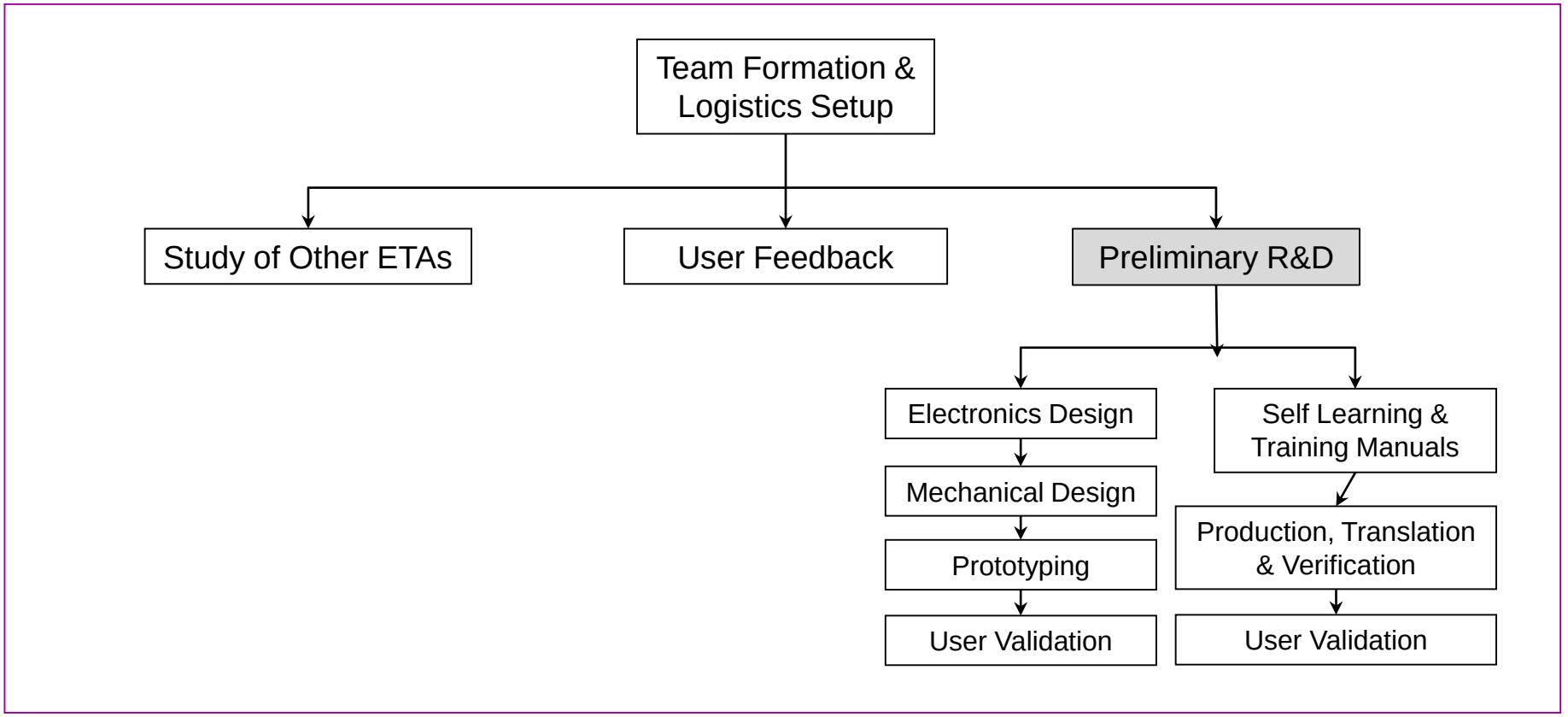
Milestone 1: Key Activities



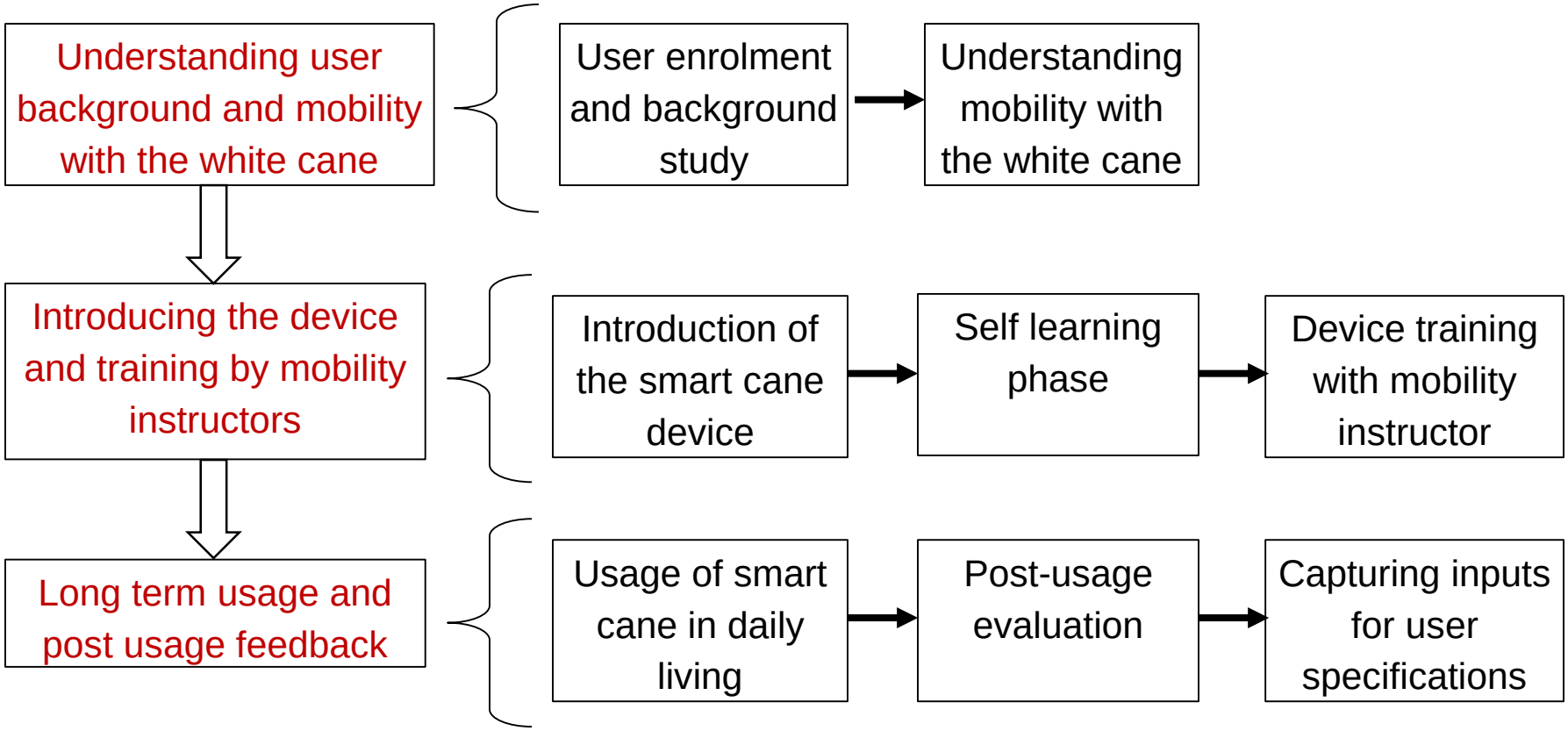
Milestone 1: Key Activities



Milestone 1: Key Activities



Qualitative feedback trials of Smart Cane



Phases of Feedback Trials

Qualitative feedback trials of Smart Cane

- Understanding of users' background
  - Extent of mobility
  - Use of technology products
- Use of white cane and its limitations
- Smart cane utility, usage, advantages, failure cases & improvements needed
- Efficacy of Smart cane training methodology
- Users' attitude, psychological impact and social acceptance
- Variation with gender, age, socio-economic background, level of blindness, occupation etc.
- Understanding complete product eco-system

Qualitative feedback trials of Smart Cane

Qualitative Study

- Users from highly varied backgrounds
- In-depth user feedback over several weeks

User group

- 30 Users, 5 towns/cities, age: 15-35 yrs.
- Varied in gender, age, level of blindness, occupation

Before and After (A-B type) Method

- White cane usage followed by Smart cane
- User acts as her/his own control

Training and usage

- Standardized module based training
- 2-3 weeks Smart cane usage, phone based feedback

Feedback Collection

- Observation on indoor and outdoor obstacle courses
- One-on-One questionnaire based interview and focus group discussions
- Assessment of learning with training modules

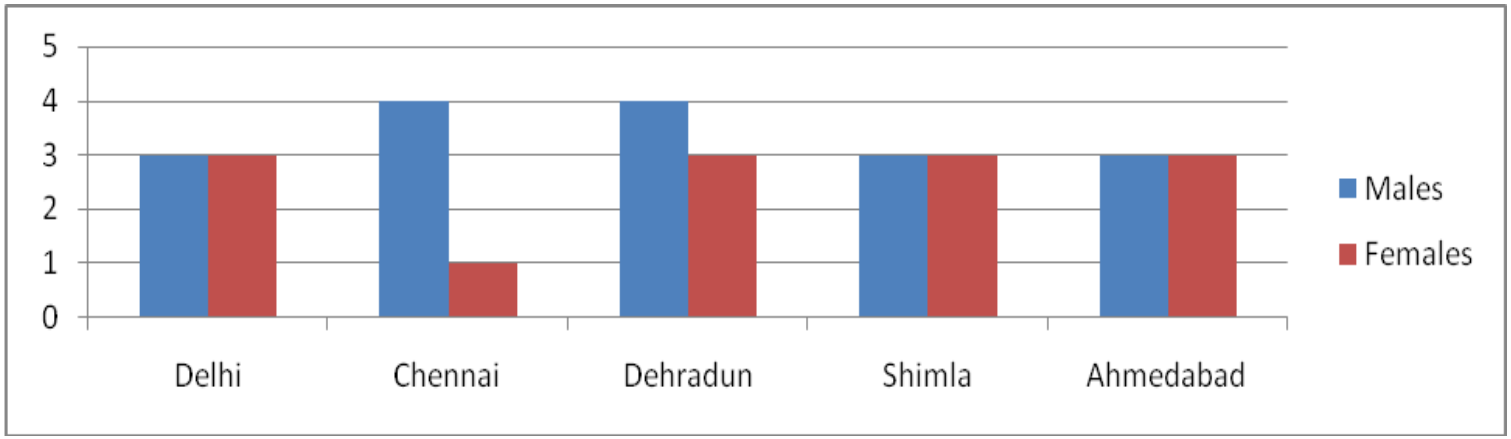
Feedback Trials

Users exploring smart cane for the first time

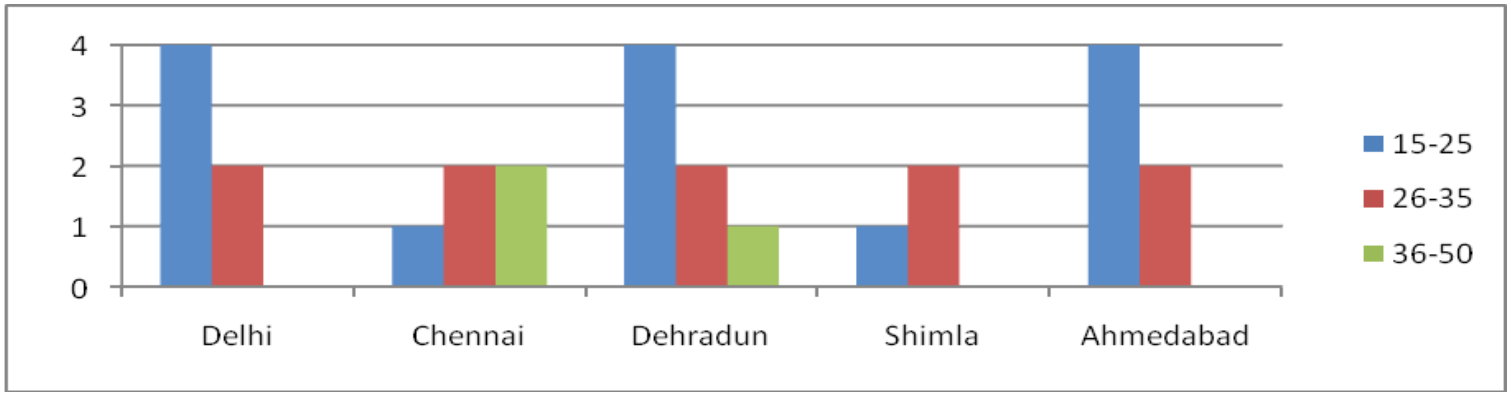
Feedback Trials

Mobility Experiments in Structured & Unstructured Environments

Qualitative feedback trials of Smart Cane



Gender distribution of user group per site



Age distribution of user group per site

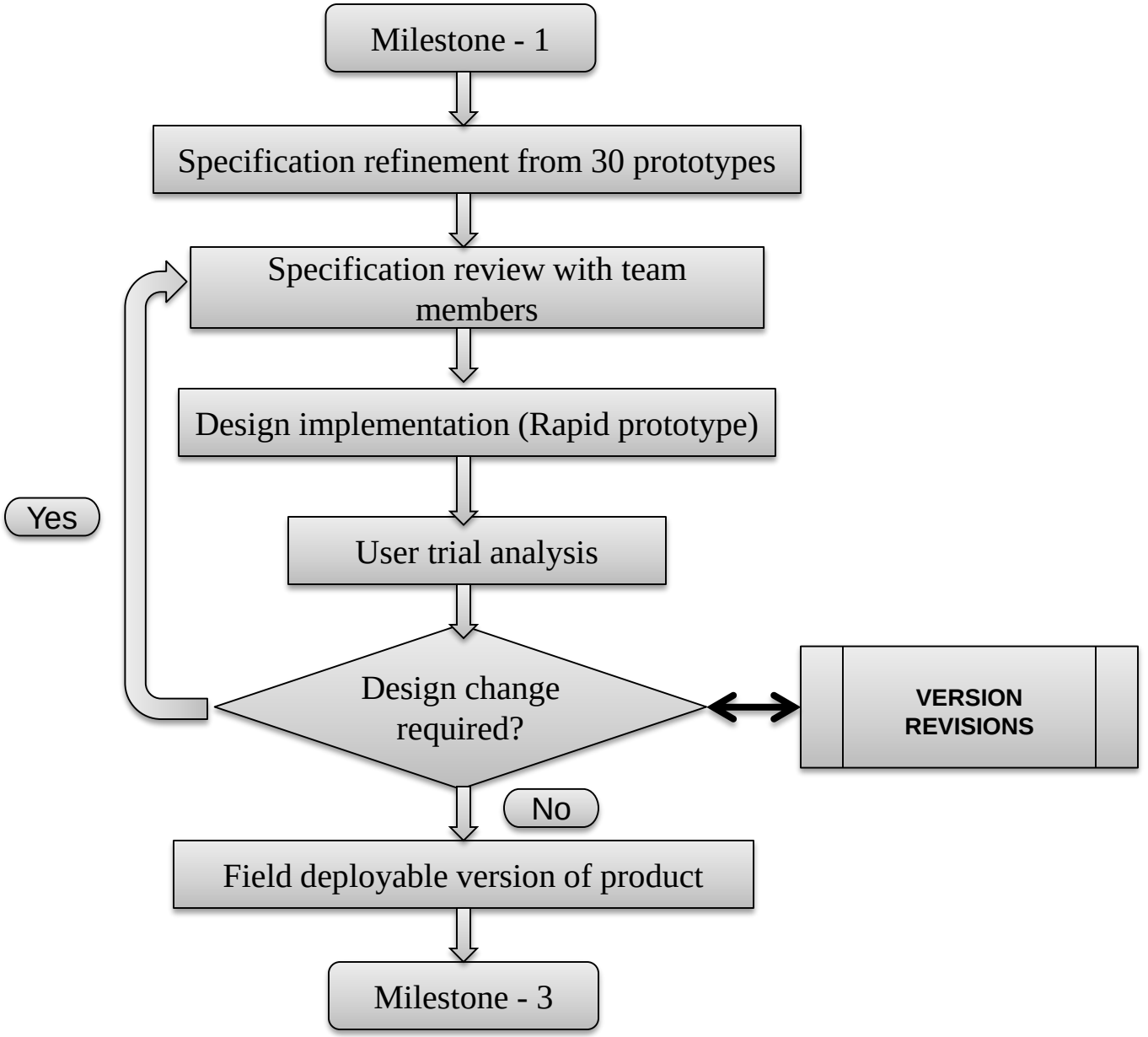
Key Findings from Feedback Trials

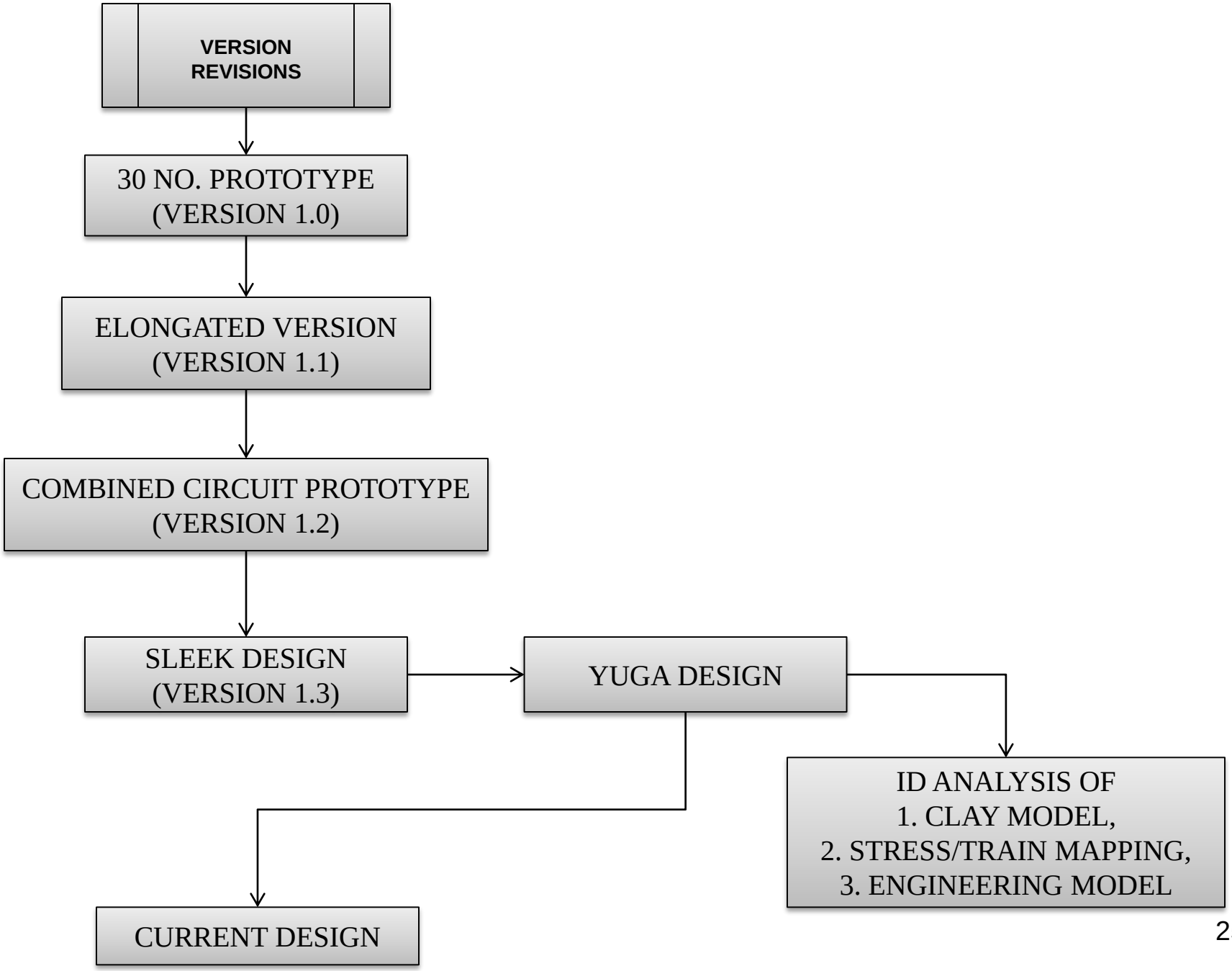
- There is an acceptance for overall concept of the device and users wanted to retain it even after the user trials got over. Some features such as intuitive tactile patterns for distance of obstacles and battery level indicators were appreciated by all.
- The device increases the confidence due to which travel time for majority of the users has reduced.
- During the study, users suggested various modifications such as reduced weight, reduced size of the device, increased tactile perceptibility, reliability in detection of head height obstacles and improved path finding abilities.
- Training is very critical for acceptance and use of this device.
- The acceptance was better among young than older people.
- Mobility for a visually challenged in hilly terrain is found be a difficult task even with white cane and blind population here depend on the sighted assistance for their mobility.

Implications from Feedback Trials

- Smart cane will be designed in such a manner that it can be mounted on white cane to keep second hand free.
- Smart cane will be the first affordable electronic travel aid and it can be made to reach of large percentage of blind population.
- All the changes suggested by users have been put in as list specifications which will guide further development.
- Model with basic features will be developed first and additional features in terms of wish list will be considered in later models.
- List of obstacles gathered from the study have been incorporated in the test cases for future field trials.
- Further efforts will be made to improve user manuals and strengthen device training methodology by mobility instructors.

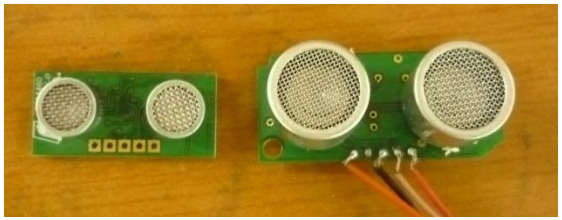
R&D DESIGN CYCLE

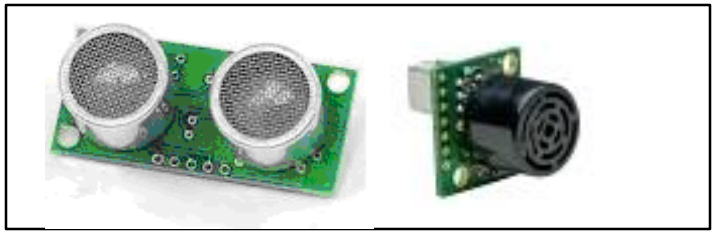


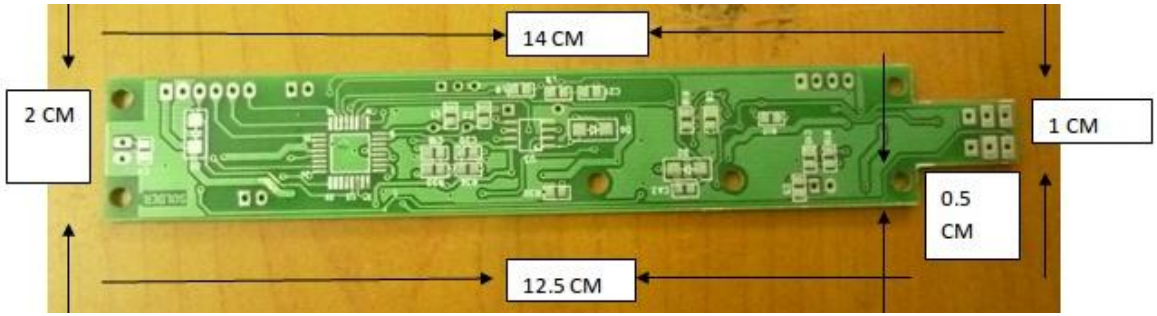

VERSION REVISIONS
30 NO. PROTOTYPE (VERSION 1.0)
ELONGATED VERSION (VERSION 1.1)
COMBINED CIRCUIT PROTOTYPE (VERSION 1.2)
SLEEK DESIGN (VERSION 1.3)
YUGA DESIGN
ID ANALYSIS OF
1. CLAY MODEL,
2. STRESS/TRAIN MAPPING,
3. ENGINEERING MODEL
CURRENT DESIGN

Product R&D (Electronics)

- Sourcing & testing smaller and water proof ultrasonic sensors.
- Exploring trans-receiver based sensors.
- Miniaturized combined electronics circuit.
- Multilayer PCB design

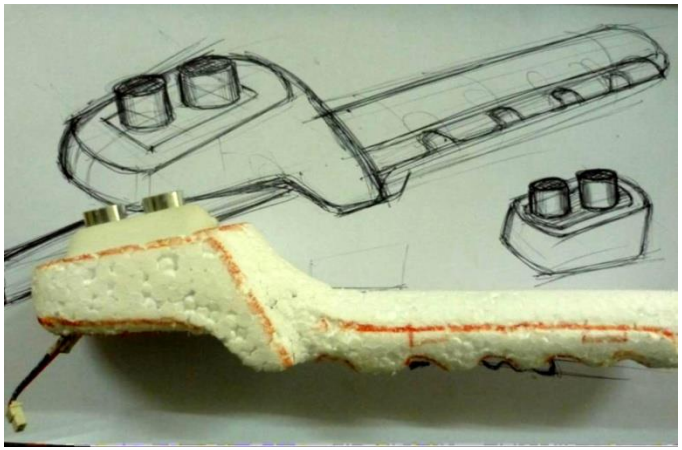


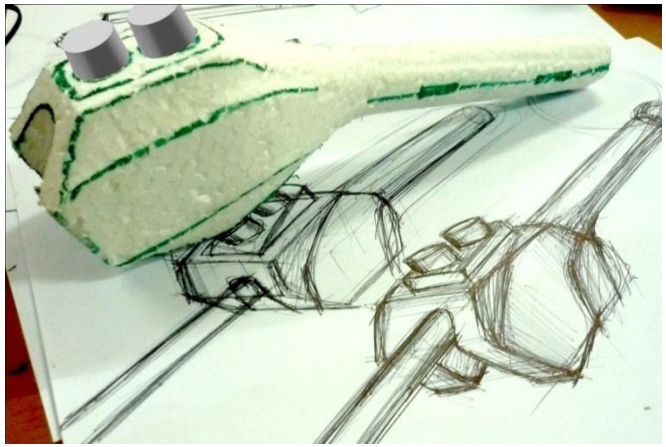




Product R&D (Mechanical Design)

Version 0.4



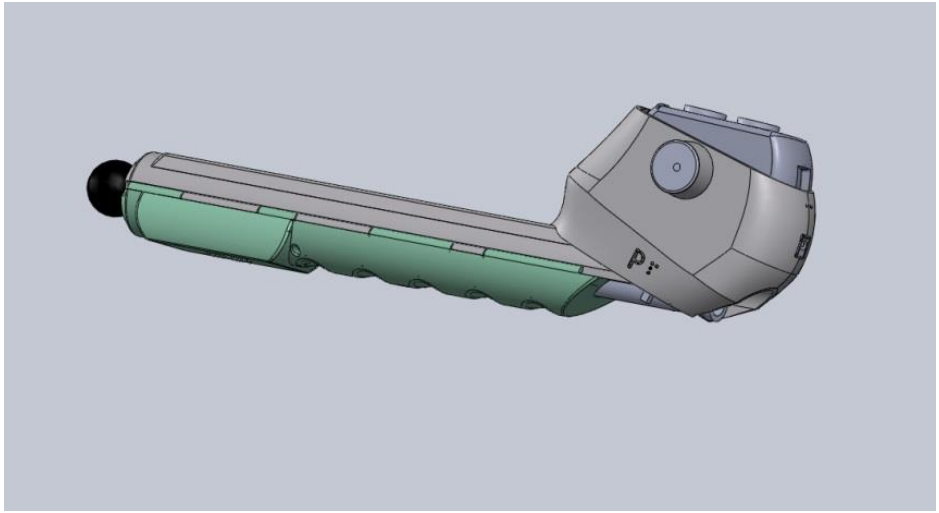


Version 0.5

Version 0.6

Version 0.7

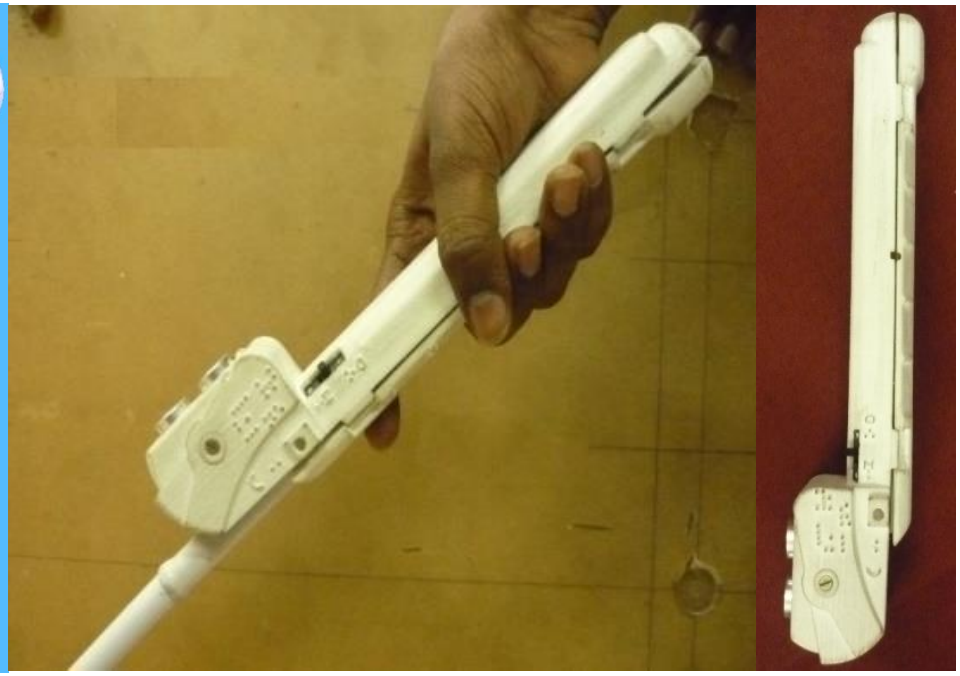
Product R&D (Mechanical Design)



Version 0.8 used for user trials

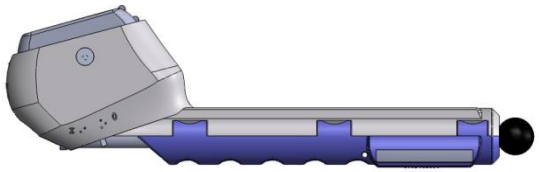
Product R&D (Mechanical Design)

- Non protruding angle adjustment mechanism
- Reduced size, thinner grip & better weight balancing
- Braille markings according to standards
- Single combined ultrasonic and control circuit

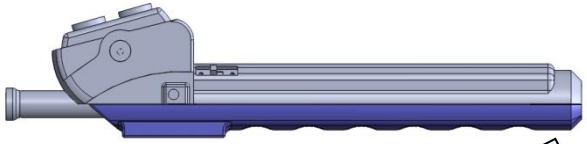


Latest Design Version 0.9

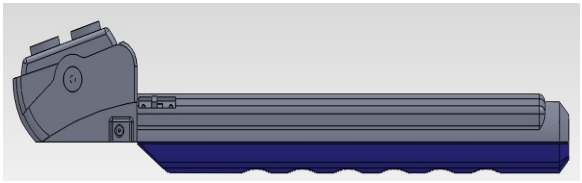
INDUSTRIAL DESIGN CYCLE



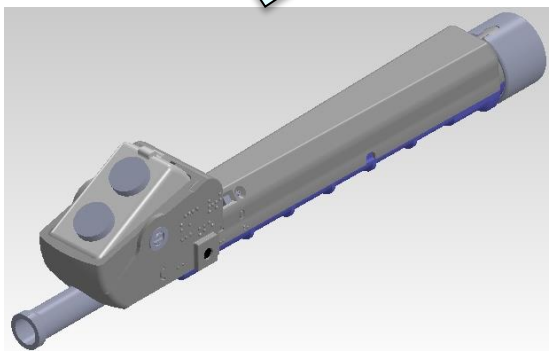
Version 1.0
Field trial prototype



Version 1.1
Elongated prototype

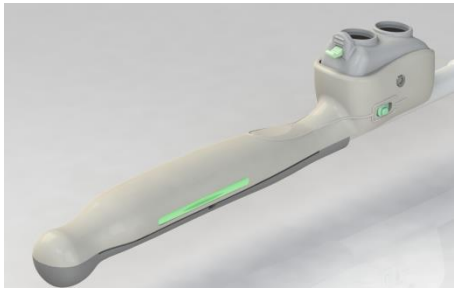


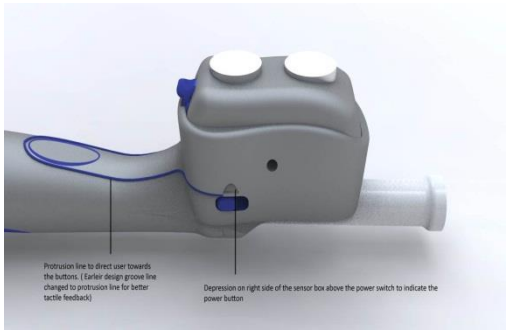
Version 1.2
Combined circuit prototype



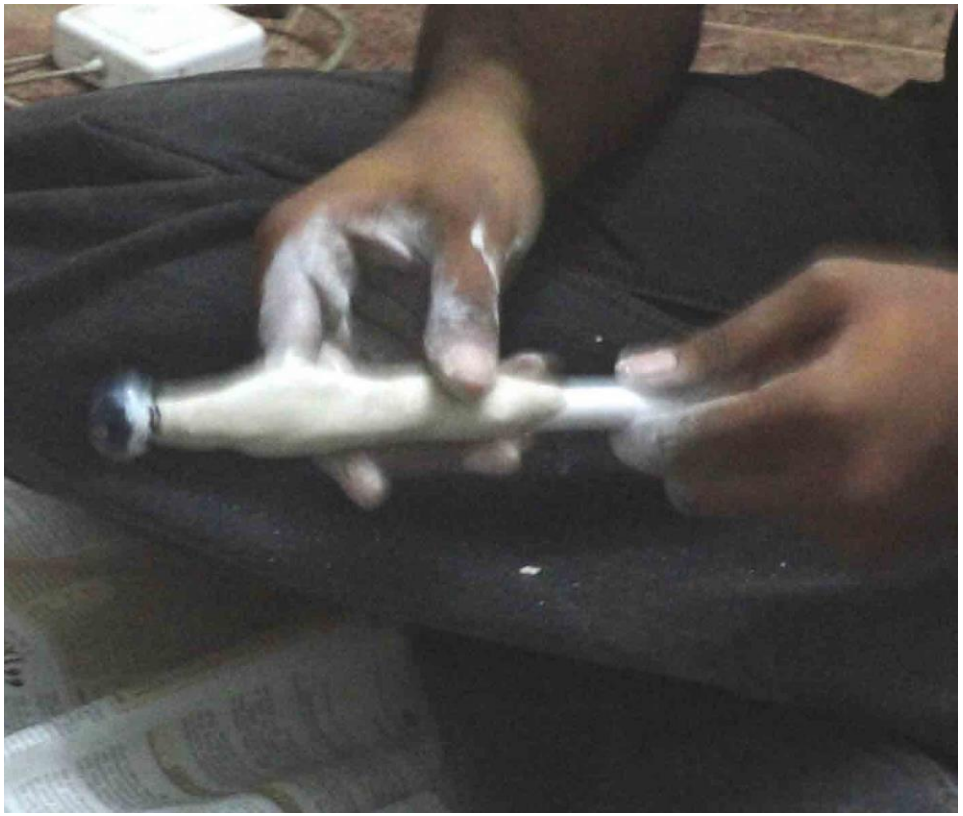
Version 1.3
Sleek design

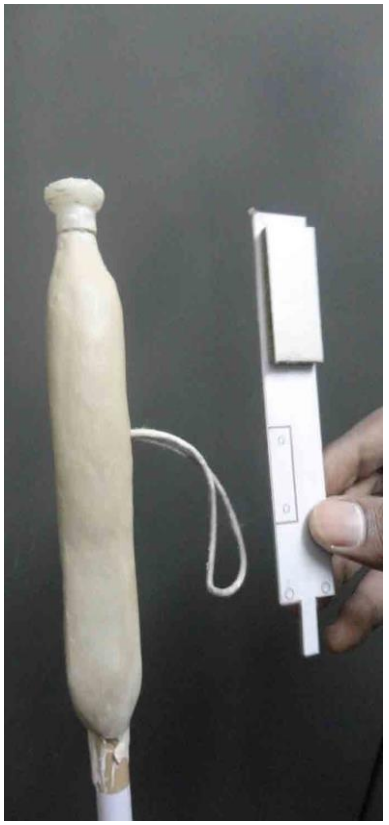
Version 2.0
Final design





Industrial Design Approach to Grip Design

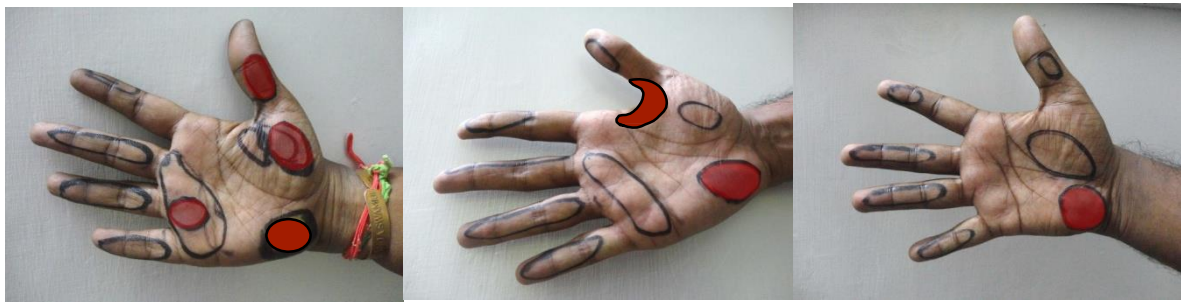




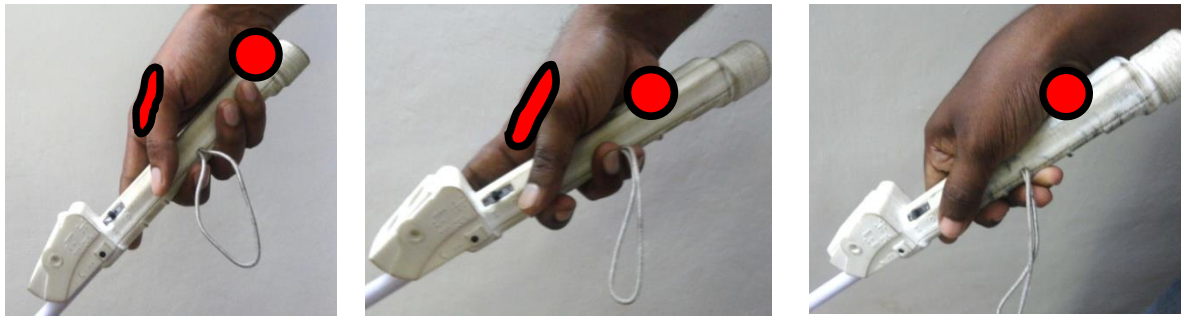
Model → Test → Remodel Iterations with users

Industrial Design Approach to Grip Design

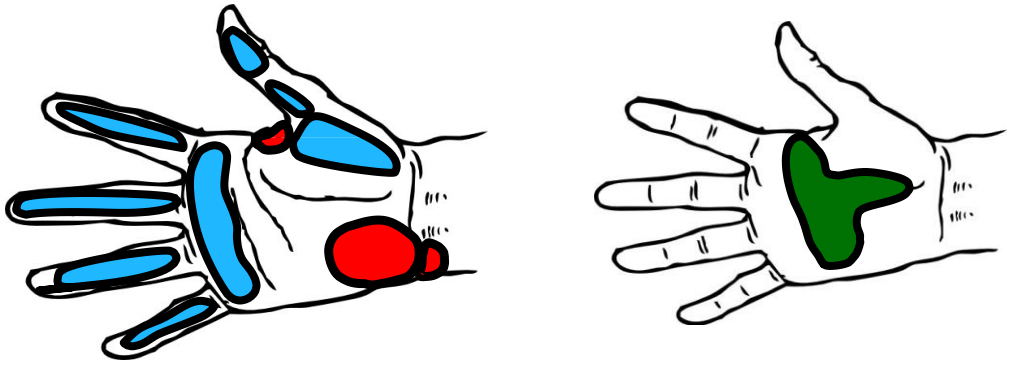
Identify pain areas in all types of grips



Identify common pain areas in all grips



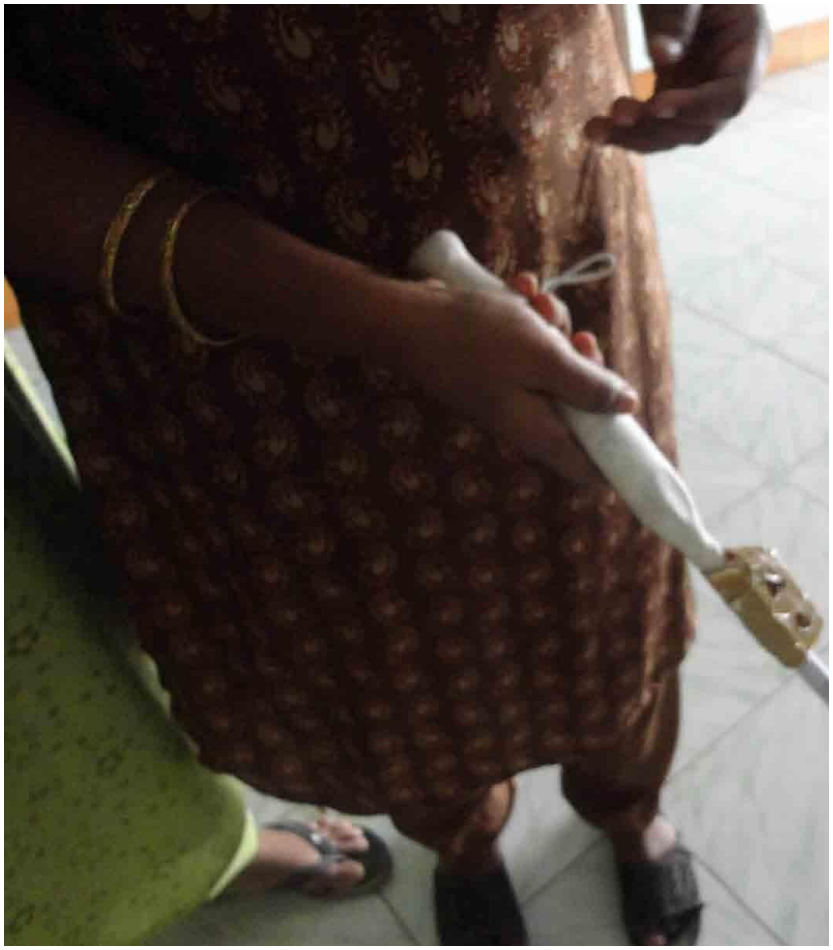
Explore other palm areas to reduce stress



Industrial Design Approach to Grip Design

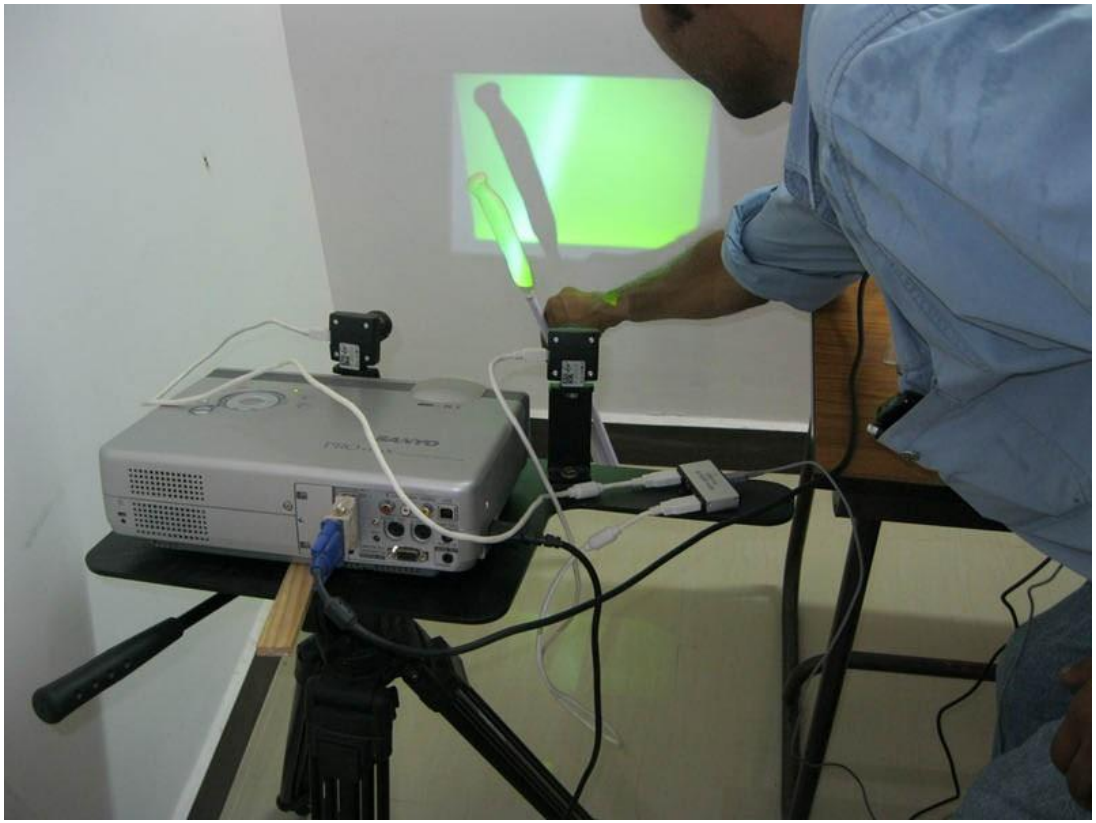
Trials with Clay Models

Industrial Design Approach to Grip Design



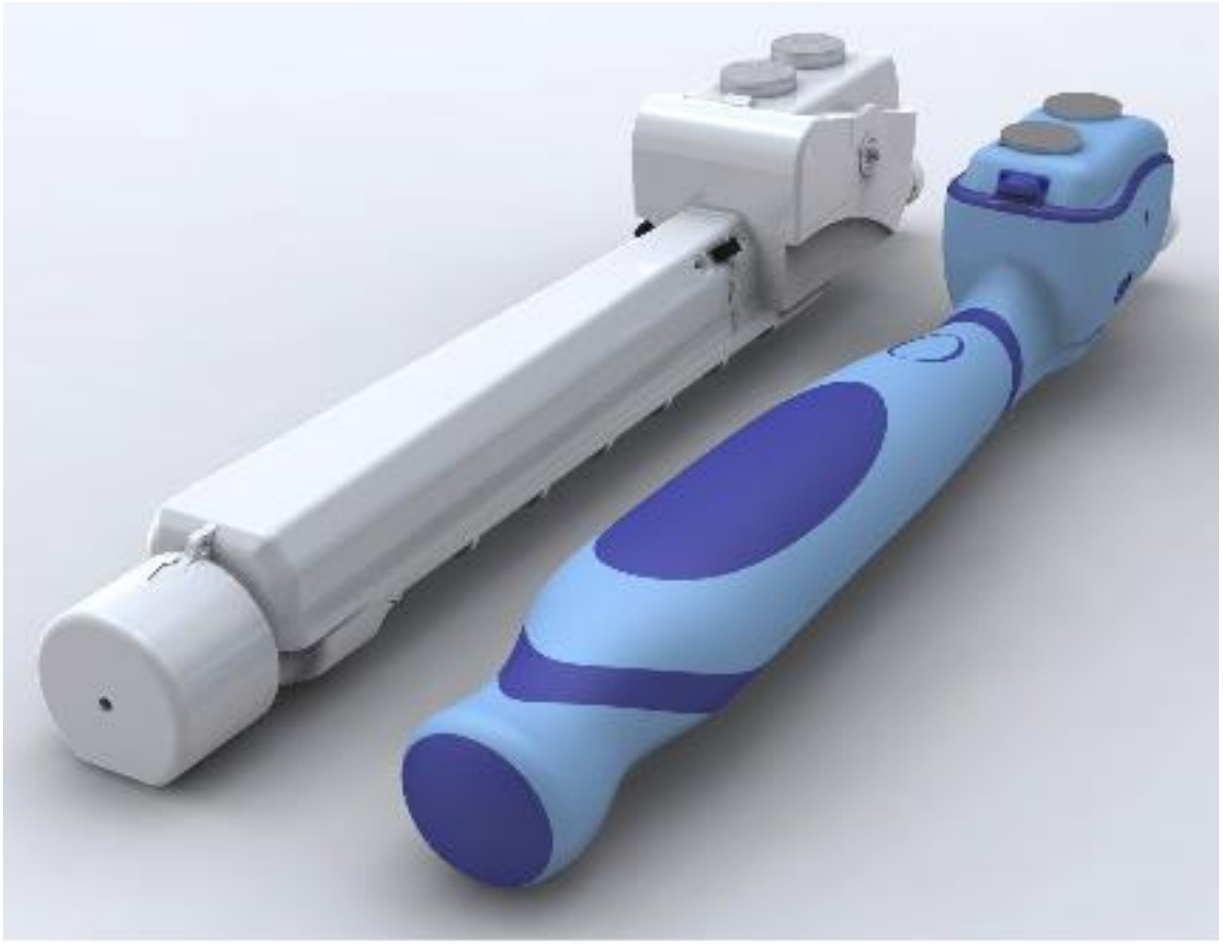
Trials with Clay Models at NIVH Chennai

Industrial Design Approach to Grip Design



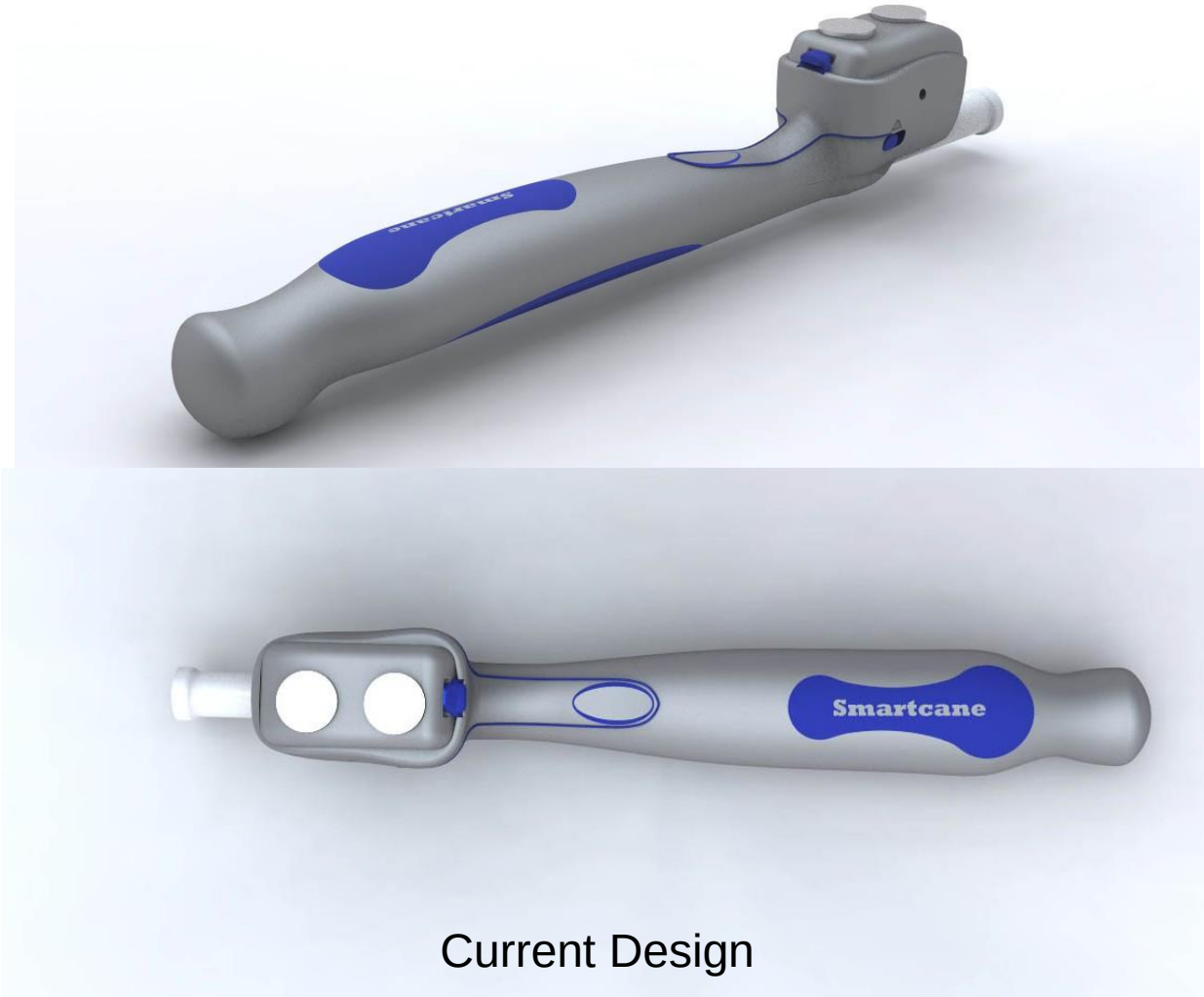
3D Digitizing Clay Models to build CAD models

New Design of Smart Cane



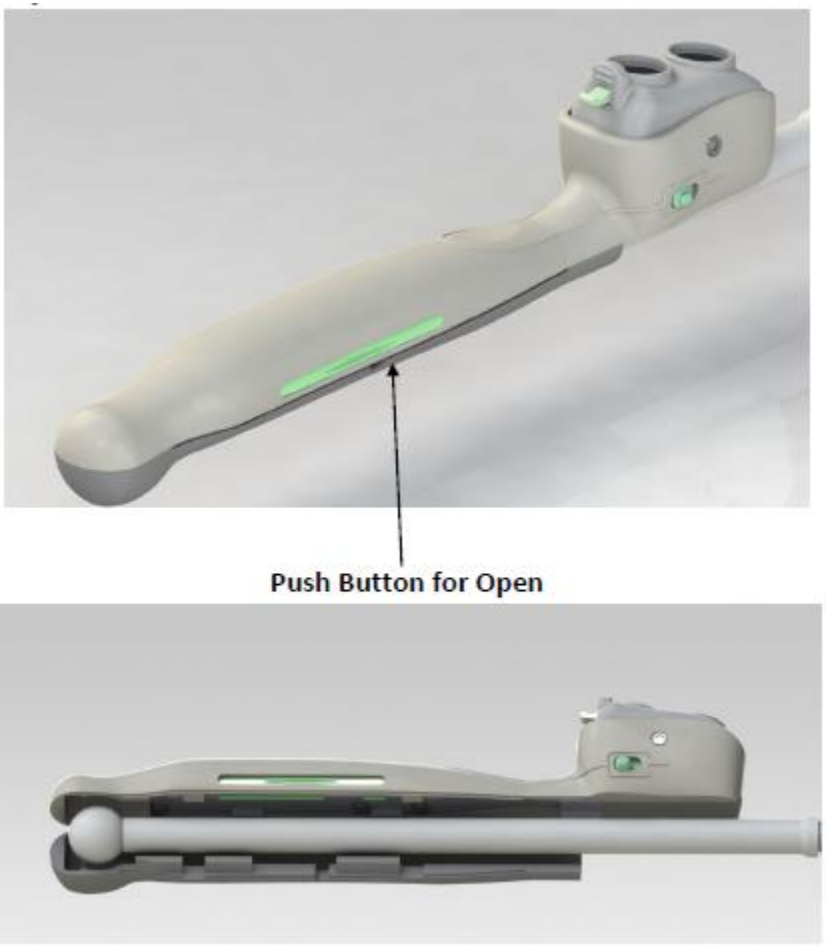
Old and New Design

New Design of Smart Cane



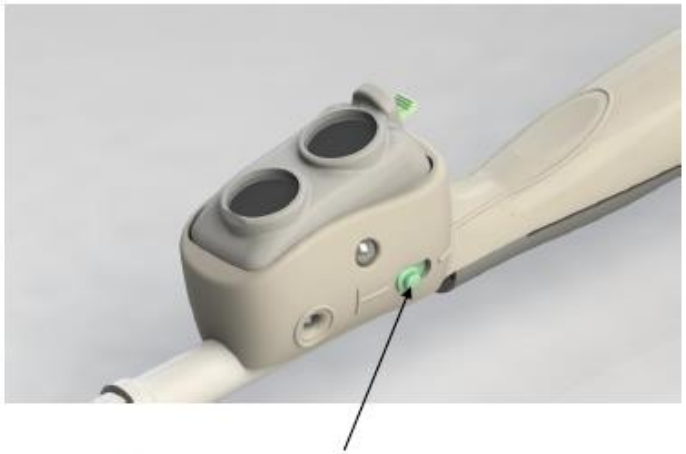
Current Design

New Design of Smart Cane

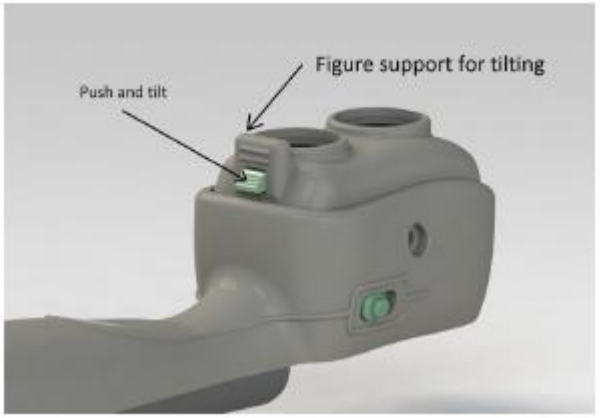


Cane attachment and Detachment Mechanism

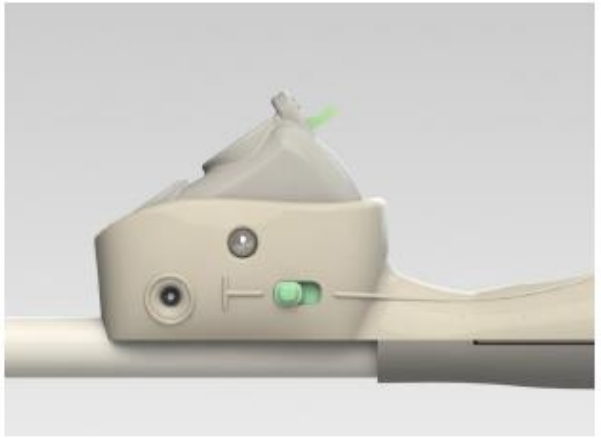
New Design of Smart Cane



Mode Selection Switch (Towards user indoor)



Charger location



Angle Adjustment Mechanism

MECHANICAL DEVELOPMENT CYCLE

Version 1.0

1. Device handling is uncomfortable and painful due to its big size and needs to be reduced.
2. Also the weight is high because the electronics is congested into the head of the smart cane, which pains most of the users to hold for a longer time.
3. Shape changes needed(unit look like gun)
4. Position of the switch needs to be changes as they find cane detachability to be difficult
5. Snap fit used to lock white cane into Smart cane is not coming out properly as it automatically opens while accidental fall down cases.

Version 1.1

1. Switch position is Good (easy to useable)
2. White cane folding is difficult (while fold the cane, battery location is hit to the cane)
3. Handle grip is not fit to children hand

MECHANICAL DESIGN CYCLE

Version 1.2

1. Battery location changed
2. Difficult to hold for long time

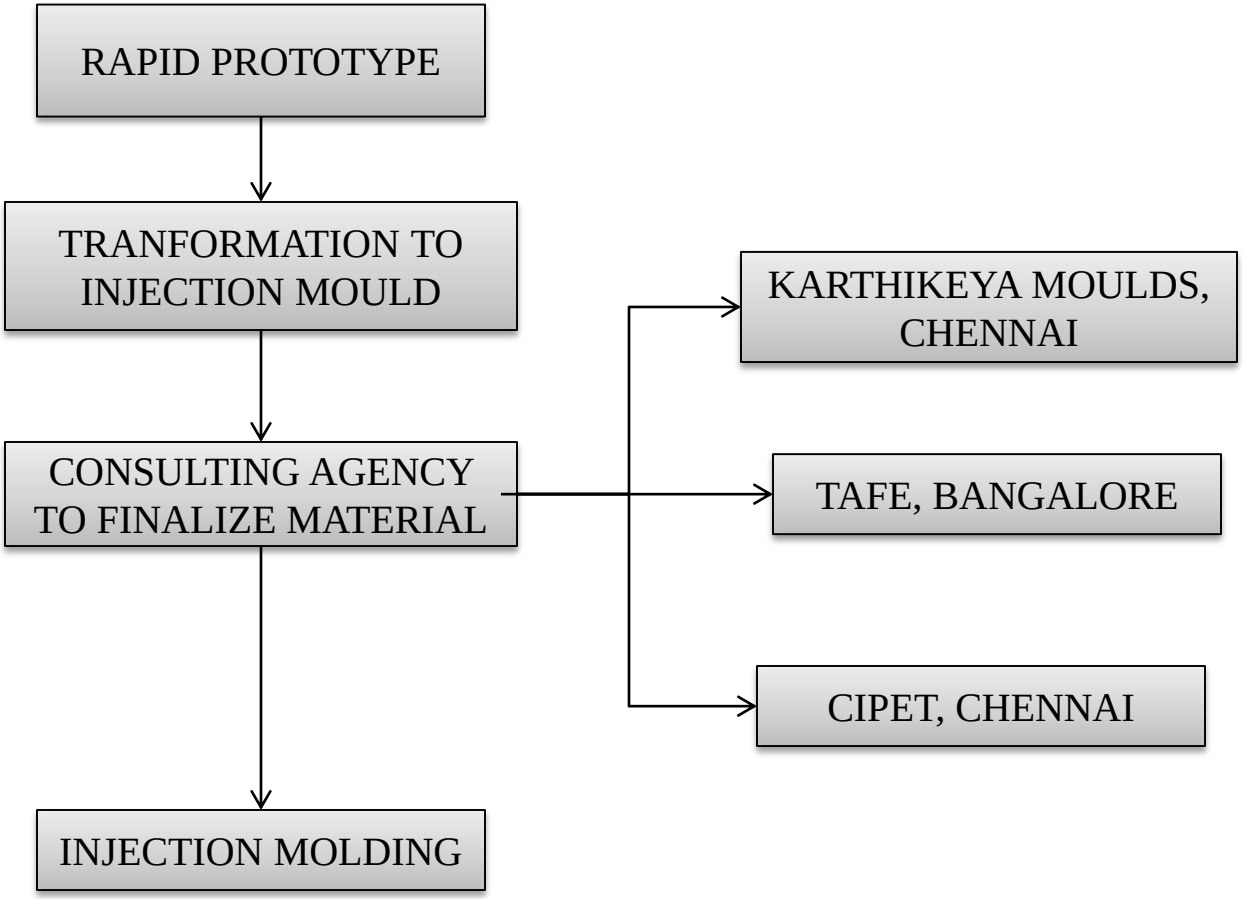
Version 1.3

1. Grip is making irritation for long time handling
2. After dismantling 4 no of component is there, after dismantling searching component is difficult.
3. Industrial design needed
4. Color for smart cane
5. Positive lock for sensor lock
6. Symbols for switch identification
7. After Dismantling not more than two component (smart cane & white cane)

Version 2.0

1. Handle grip fit for small and large size of hand
2. Good look
3. Positive sensor lock is easy to useable
4. Cane dismantling is easy
5. Weight less

INJECTION MOLD & MATERIAL SELECTION



Molding process

Mechanical Components

Assembly at Phoenix Medical Systems

DESIGN & DEVELOPMENT IN ELECTRONICS

Version 1.0

1. Design transfer directly from IIT prototype
2. Fuel gauge IC implemented for battery level identification
3. Component size optimized
4. Vibrator changed for better intensity
5. Sensor PCB re-designed for cost reduction factors to replace third party sensor boards
6. Charger adaptor implemented replaced USB interface

Version 1.1

1. PCB size re-designed due to ID constraints
2. No electronic design change

Version 1.2

1. Sensor circuit is incorporated in Main PCB
2. Ultrasonic sensor implemented Part name: 400 ST/R 160
3. Electronic components optimized
   - For cost factor
   - Power constraint

Version 1.3

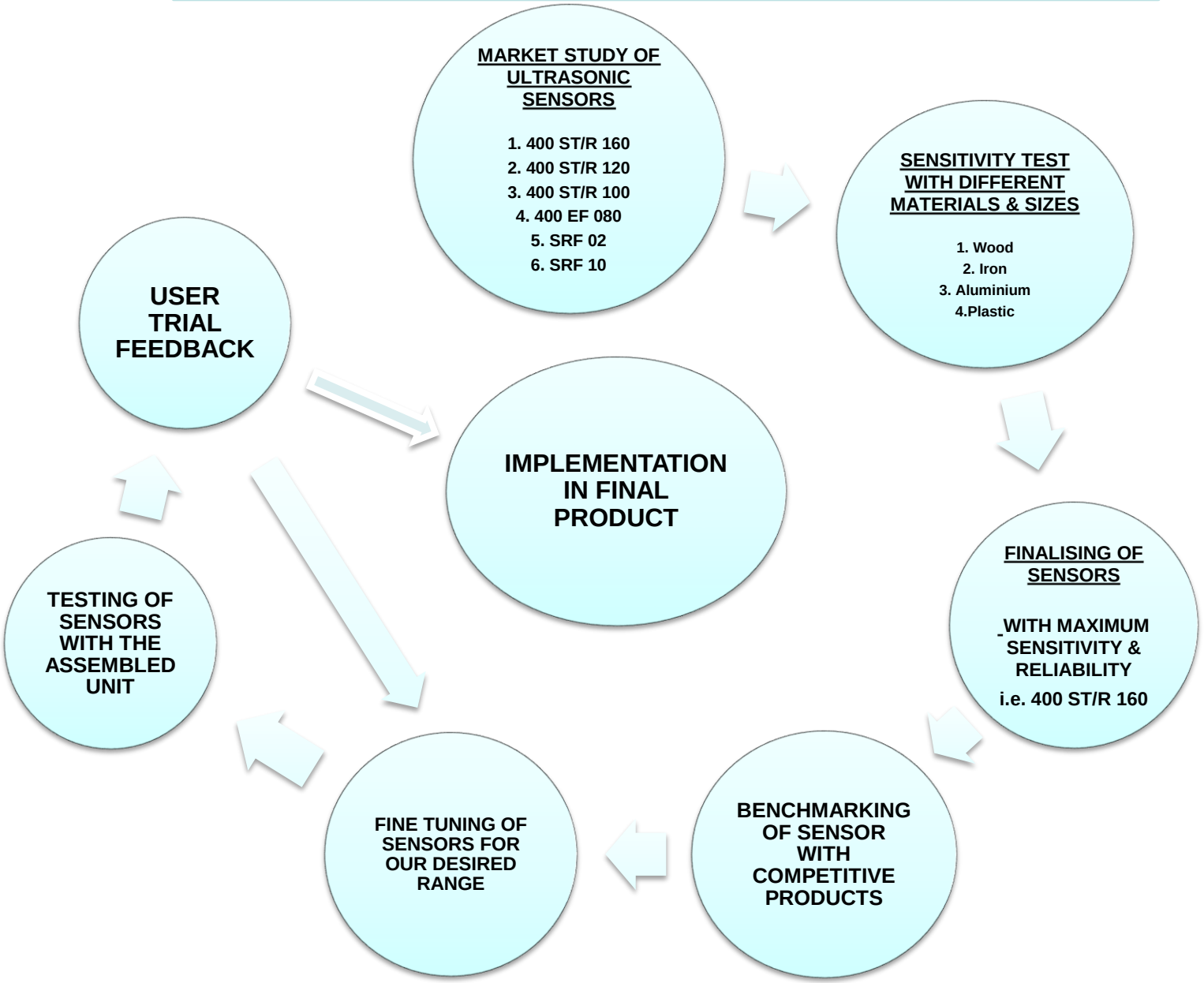
1. PCB size re-designed due to ID changes
2. Sensor circuit was given new PCB due to space constraints

Version 2.0

1. Handle grip fit for small and large size of hand
2. Good look
3. Positive sensor lock is easy to useable
4. Cane dismantling is easy
5. Weight less

HARDWARE REVISION HISTORY

SENSOR DESIGN CYCLE



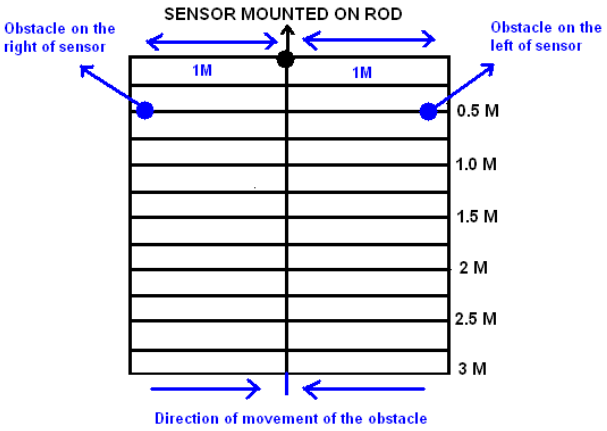
In House testing

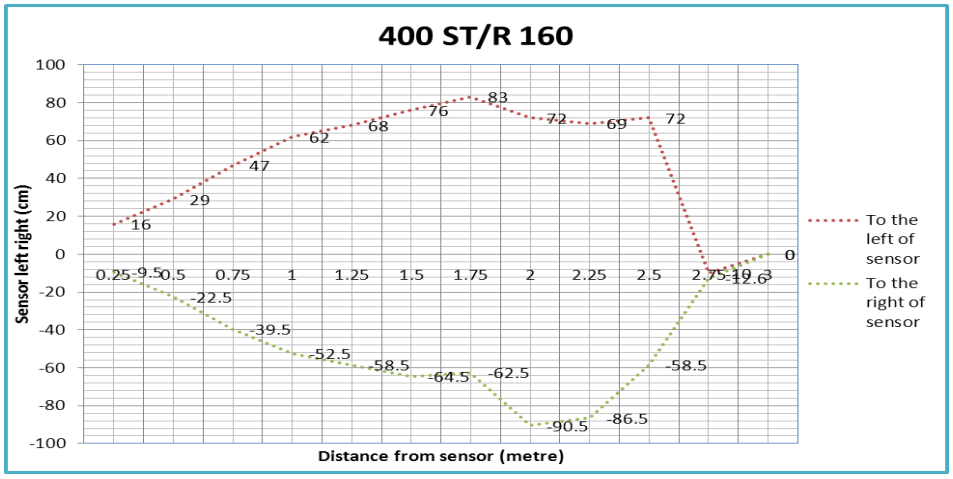
TESTING SETUP

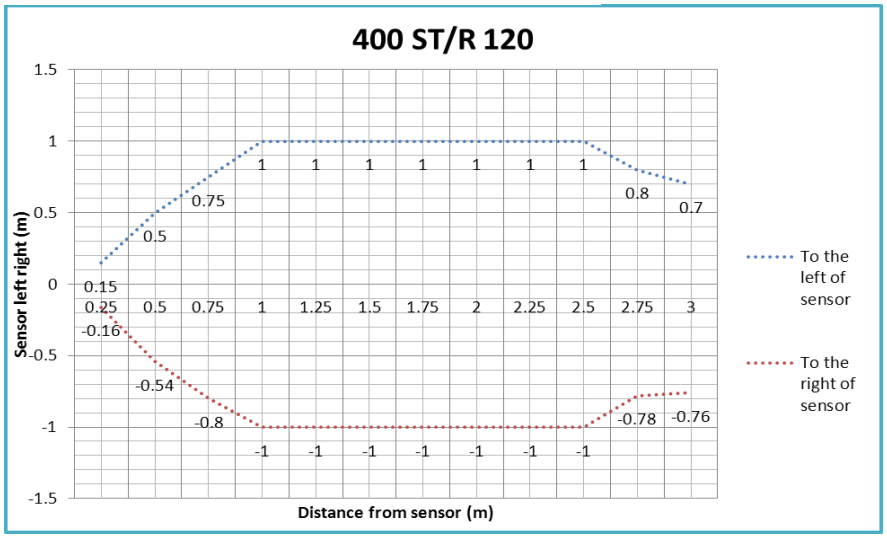
Testing Area for Sensor Field of View

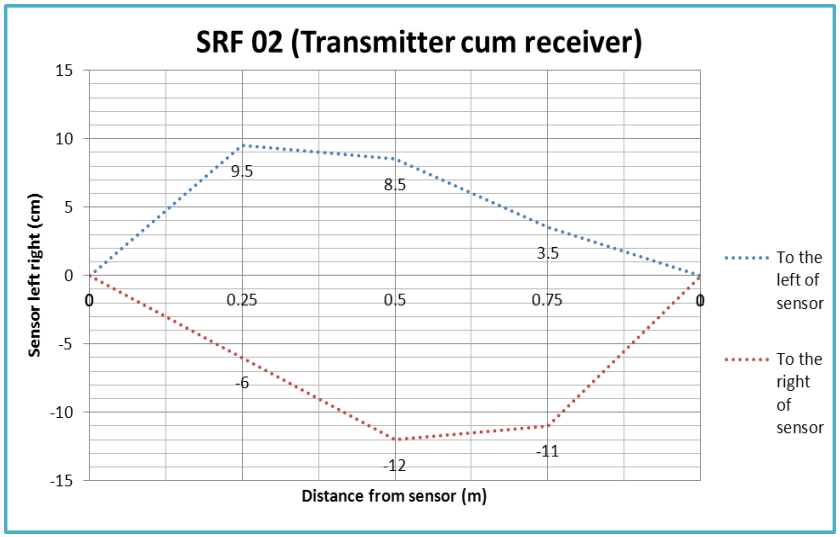
DOWEL CONE ANGLE STUDY

EXAMPLES ➔

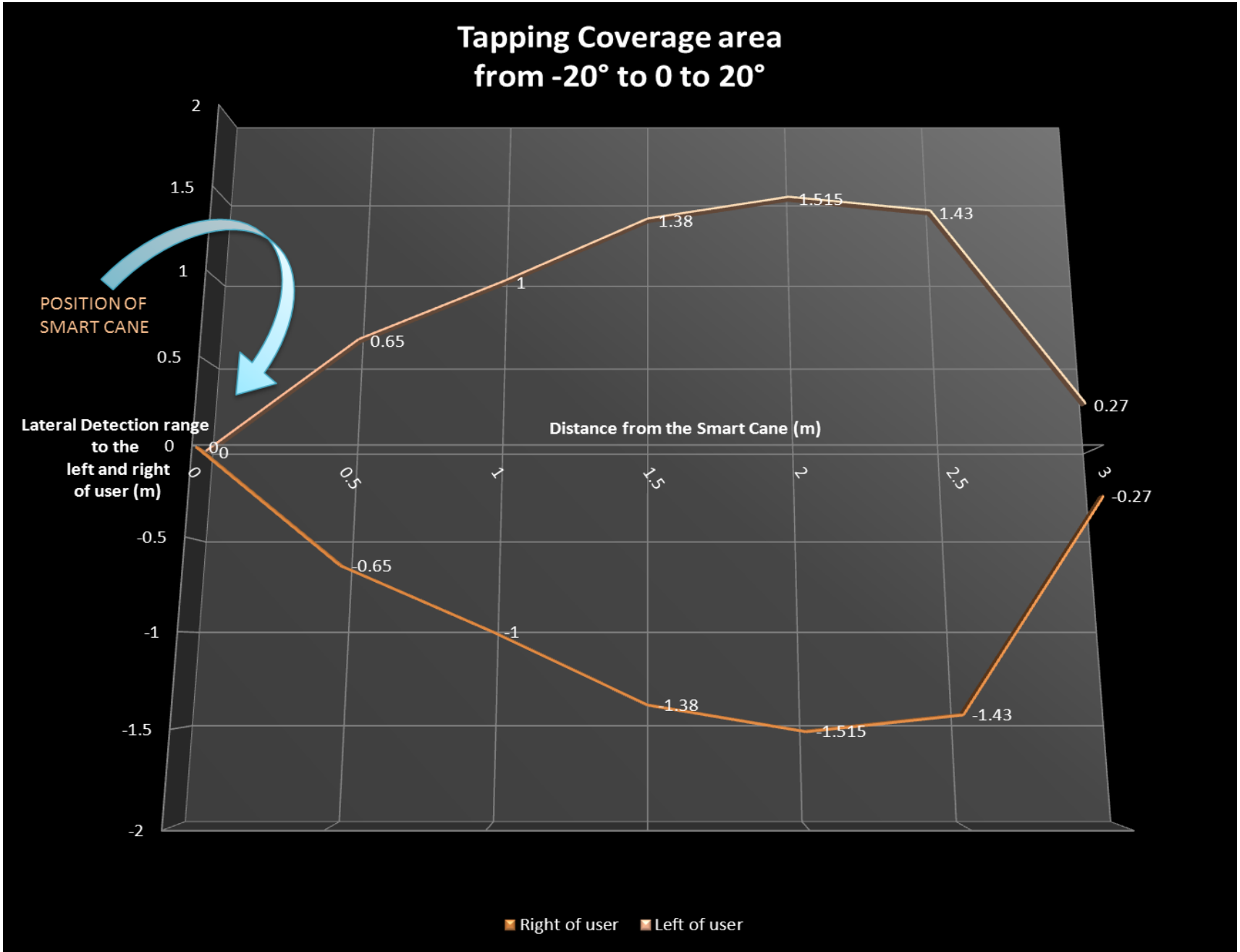




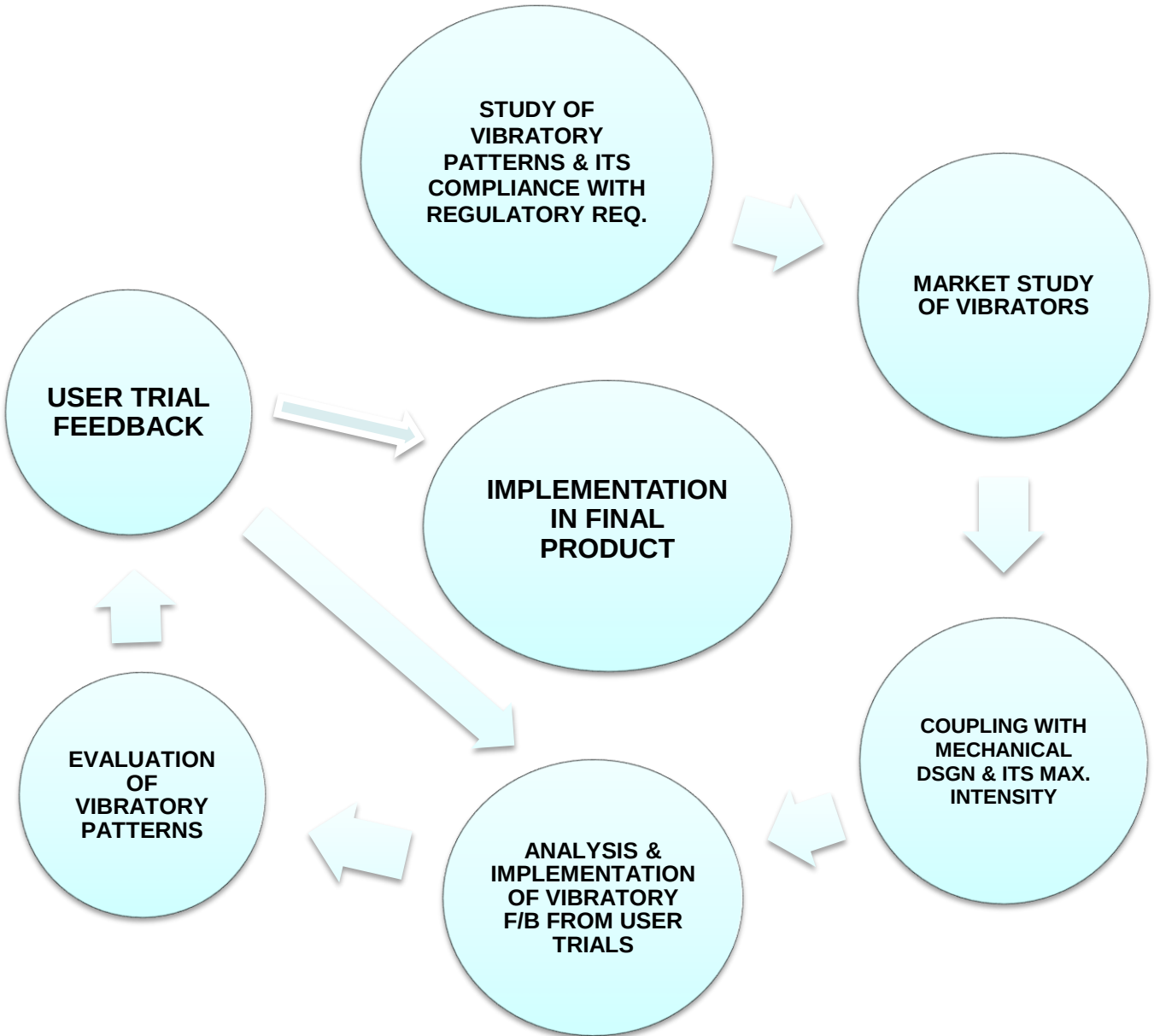




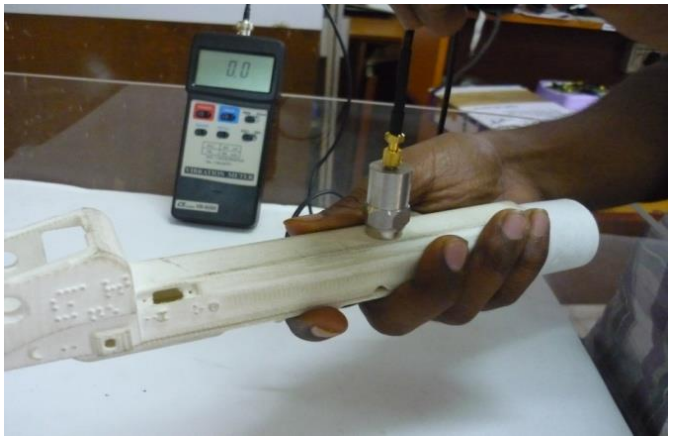
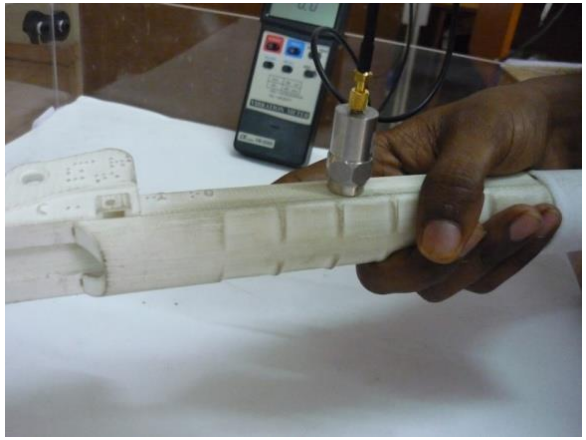
Path Finding Experiments



DESIGN OF VIBRATORY PATTERN



VIBRATORY PATTERN ANALYSIS

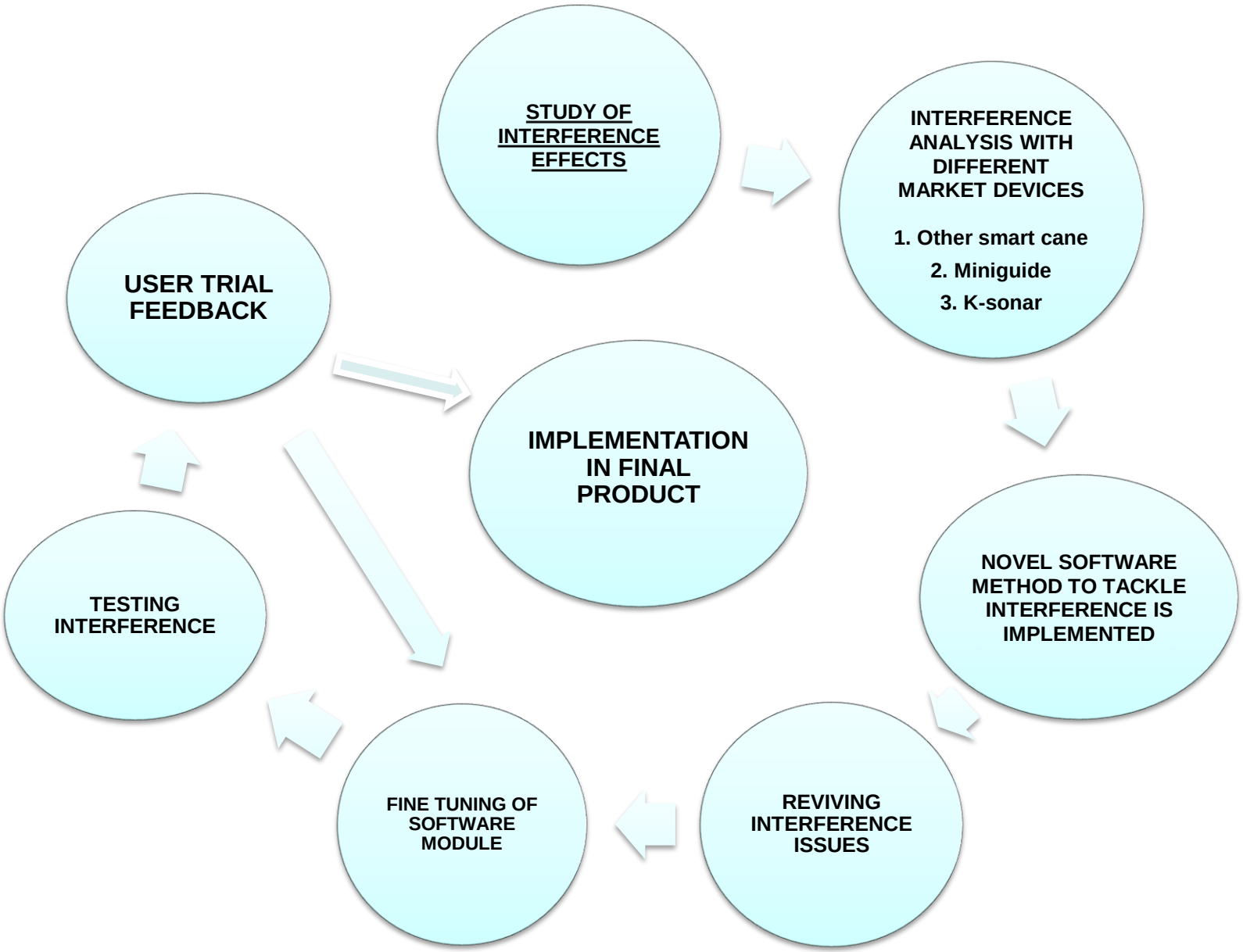




Vibratory Tests

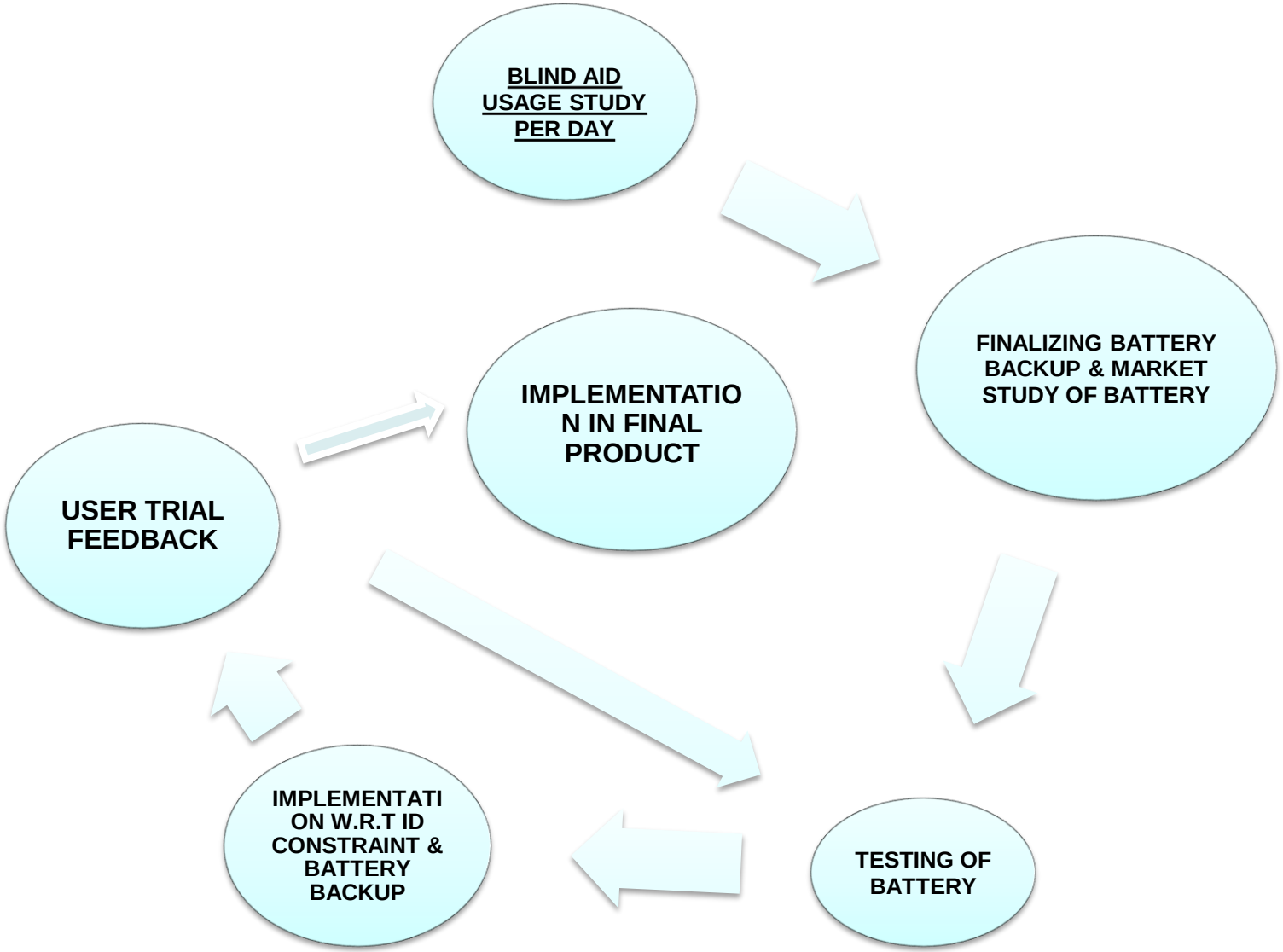
Bench Marking Studies

Smart cane ➔ 1.145 m/s²
Mini guide ➔ 4.27 m/s²
Samsung Cell Phone ➔ 2.78 m/s²
Nokia Cell Phone ➔ 0.8454 m/s²

INTERFERENCE DESIGN CYCLE



BATTERY DESIGN



Version 1.0
1. Fuel gauge software module was implemented for battery level status and alarms
2. Ports are re-assigned due to component package changes

Version 1.1

1. No software changes

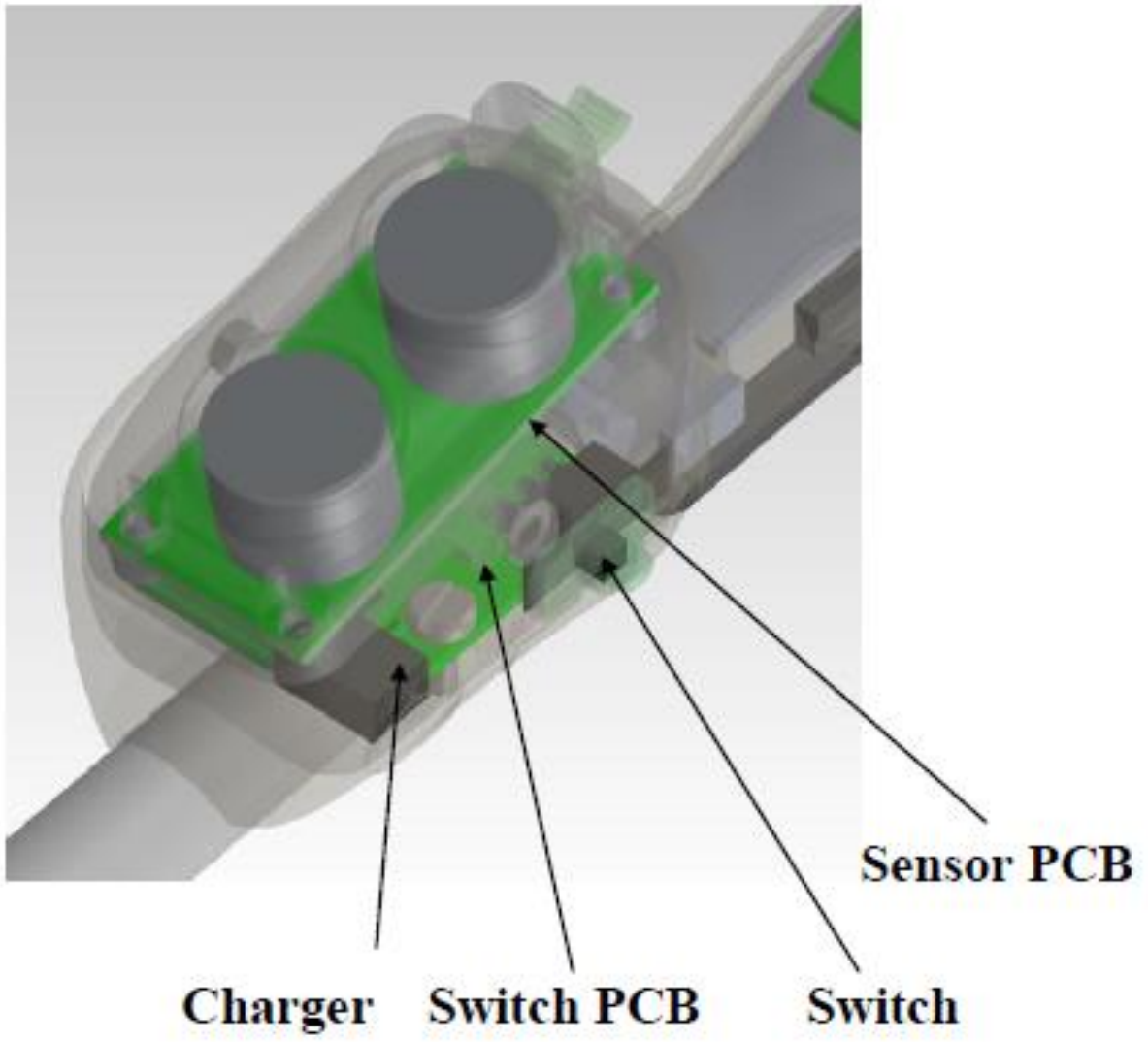
SOFTWARE REVISION HISTORY

Version 1.2
1. Software re-written for atmega-8L microcontroller
2. Range detection module was written into the main software and with performance optimizations
3. 4 Outdoor patterns was changed to 3 patterns, 3 Indoor patterns was changed to 2 patterns as per user feedback

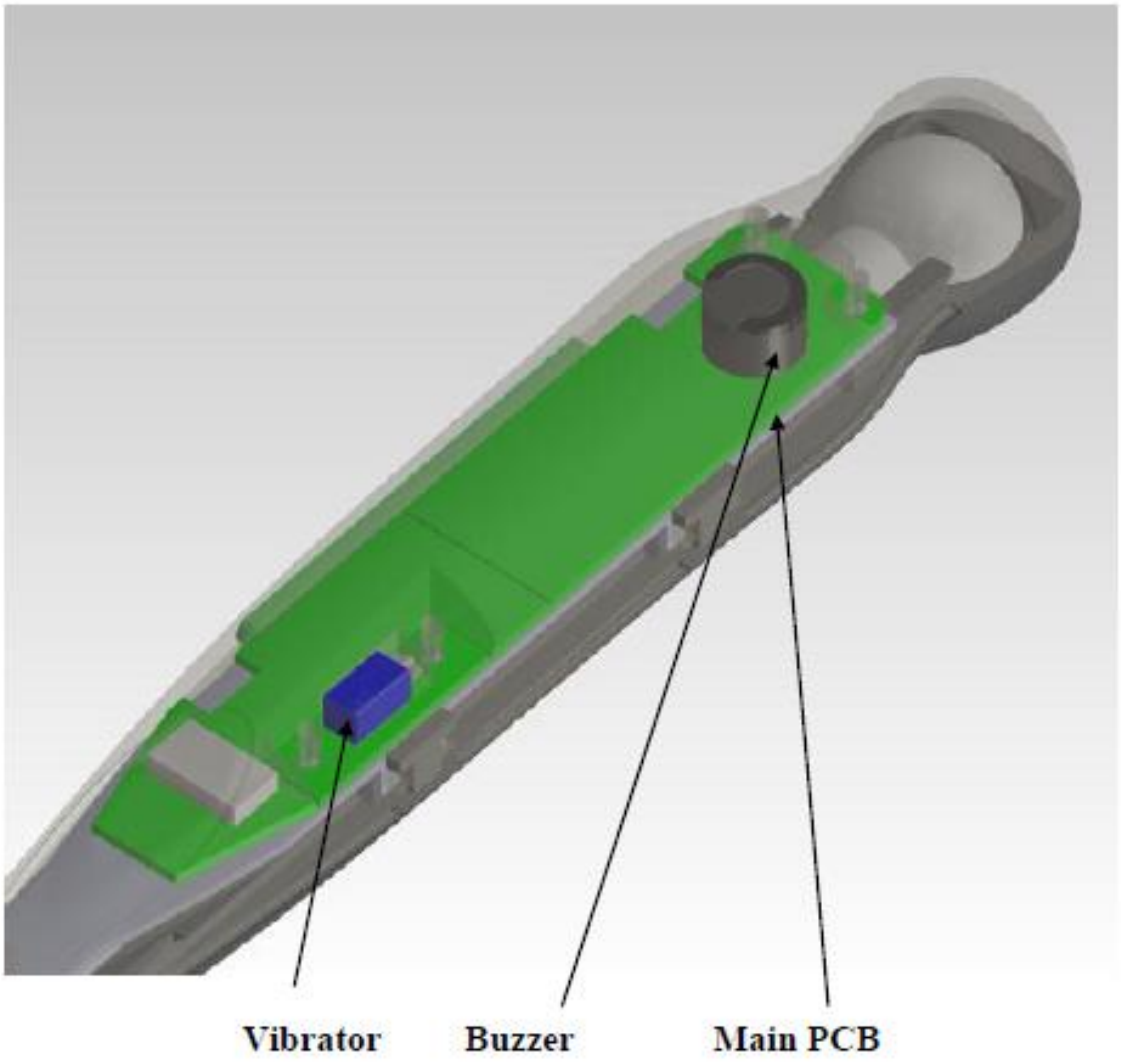
Version 1.3
1. Vibration intensity was increased
2. Interference issue was resolved with other smart cane
3. Power On self-test was implemented
4. Beep sounds for mode change was implemented
5. Charger indication module was modified

Version 2.0
1. Watch dog timer module
2. implemented
3. Vibrator sensing module was implemented
4. External communication for debugging Rx Tx
5. Fast moving obstacle detection
6. Interference optimizations

Electronics Design



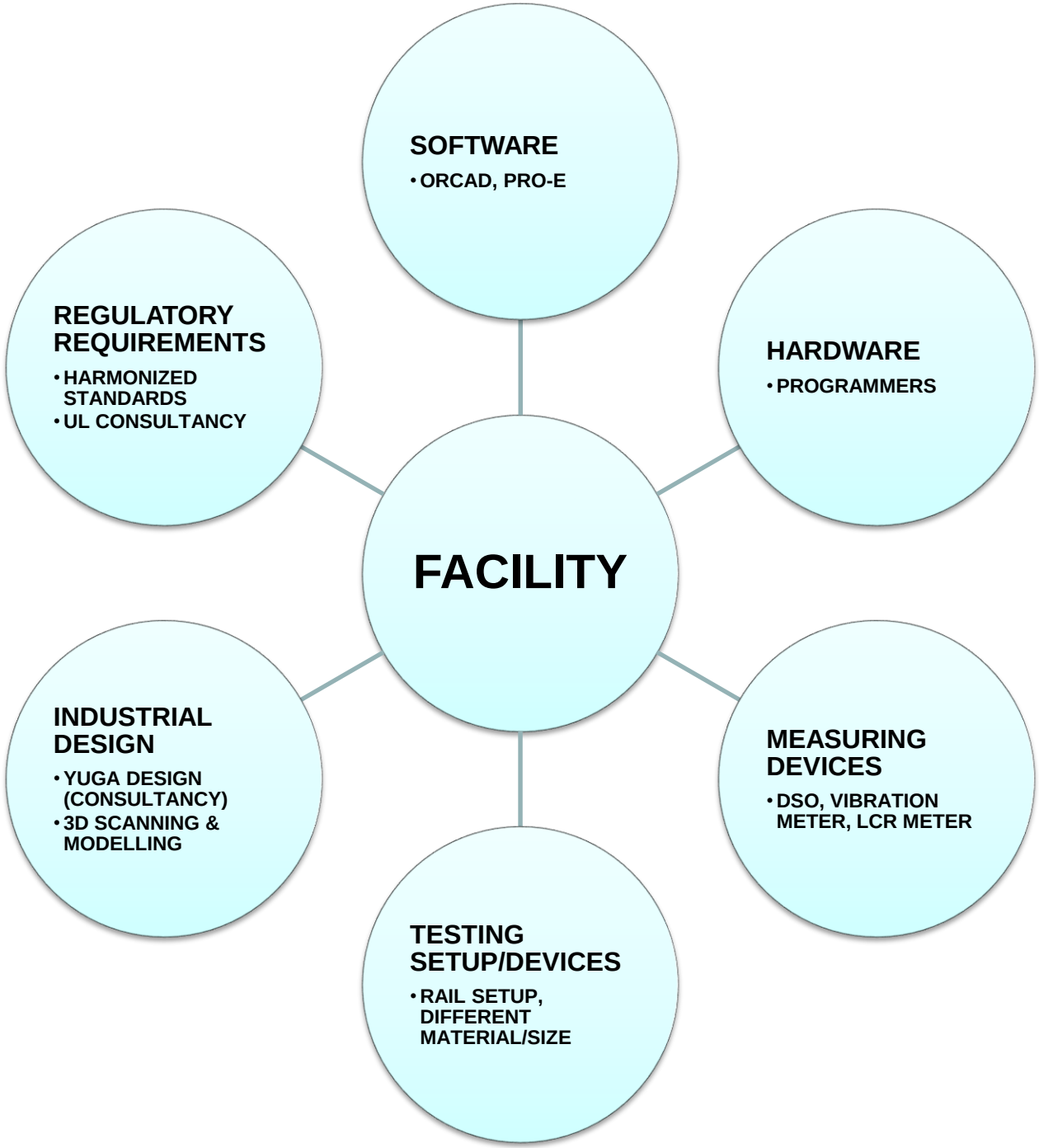
Electronics Design



Electronics Final version

Salient Features of Current Version

- Reduced size
- Reduced weight
- Improved weight balancing
- Ergonomic grip
- Improved angle adjustment mechanism
- Braille markings according to standards
- Easily accessible controls
- combined ultrasonic and control circuit with reduced size

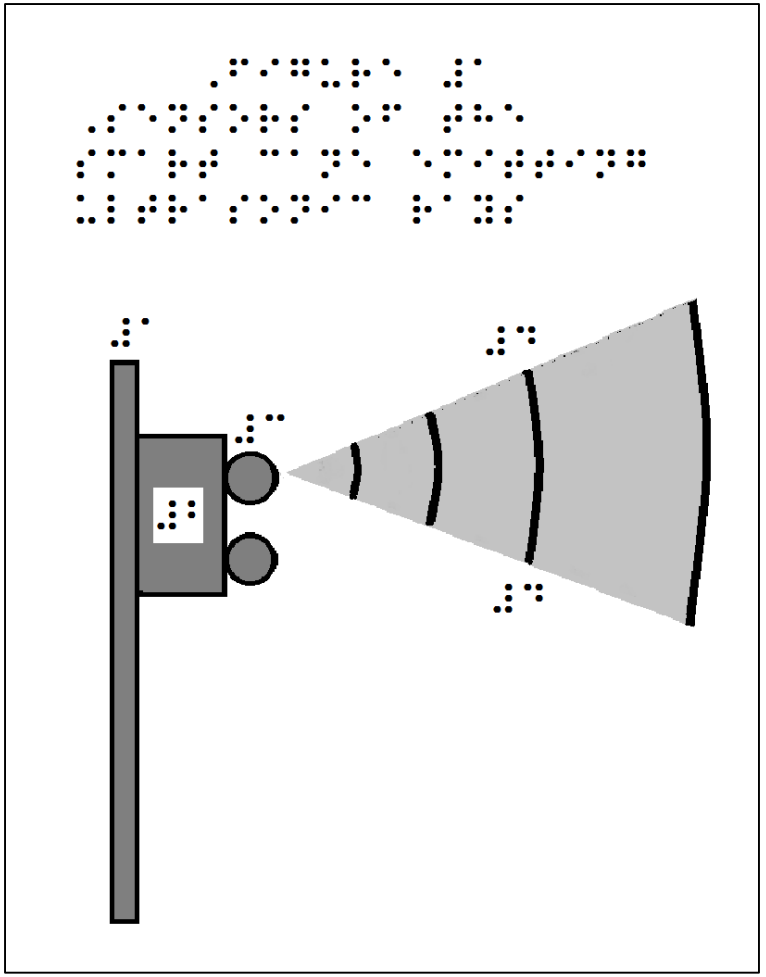

SOFTWARE
• ORCAD, PRO-E
REGULATORY REQUIREMENTS
• HARMONIZED STANDARDS
• UL CONSULTANCY
HARDWARE
• PROGRAMMERS
FACILITY
INDUSTRIAL DESIGN
• YUGA DESIGN (CONSULTANCY)
• 3D SCANNING & MODELLING
MEASURING DEVICES
• DSO, VIBRATION METER, LCR METER
TESTING SETUP/DEVICES
• RAIL SETUP, DIFFERENT MATERIAL/SIZE

CE Marking Requirements Identified

CLASS	SUB CLASS
IEC 60601-1 ed3.0	Medical electrical equipment - Part 1: General requirements for basic safety and essential performance
IEC 62304 ed1.0	Medical device software - Software life cycle processes
ISO 14971:2007	Medical devices-Application of risk management to medical devices.
IEC 60601-1-2 ed3.0	Medical electrical equipment - Part 1-2: General requirements for basic safety and essential performance -Collateral standard: Electromagnetic compatibility - Requirements and tests
IEC 60601-1-6 ed3.0	Medical electrical equipment - Part 1-6: General requirements for basic safety and essential performance - Collateral standard: Usability
BS EN 12182:1999	Technical aids for disabled persons.General requirements and test methods. Directive 2007/47/EC to be also considered
BS EN 1985:1999	Walking aids. General requirements and test methods
EN 980: 2008	Symbols for use in the labeling of medical devices
EN 1041: 2008	Information supplied by the manufacturer of medical devices.
IS 11646-2: 1986	Specification for Cane for Visually Handicapped – Part 2 : Folding Type

User Self Learning Manuals

- User self-learning manuals were improved based on feedback from previous user trials.
- Manual with tactile diagrams.
- Manual for low vision version personnel.
- Multi-lingual version of manuals

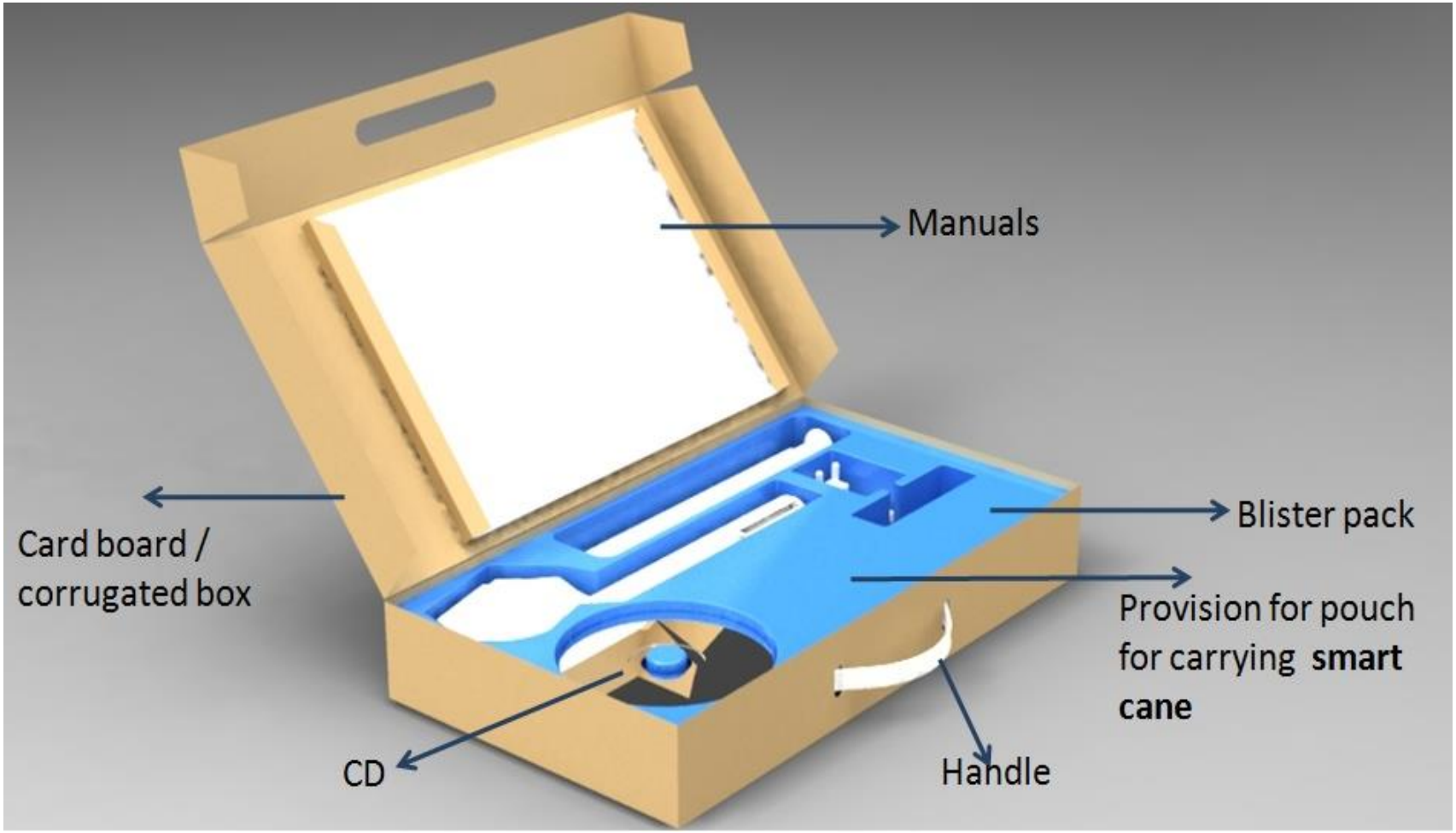


User Self Learning Manuals

Packaging & Pouch

Packaging & Pouch

Packaging & Training Manuals



Product Training

User Self-learning Manual

- Device description and exercises developed from user's perspective
- User can read and learn without any external sighted assistance (*major innovation*)

Trainers' Manual

- Written for mobility instructors and sighted family members to assist user

Practical Training Modules

- Module based teaching curriculum for training the user in Smart cane use in a *hand's on* way
- Training for 4 hours over 2 days involving mobility instructors
- Learning material made available in several formats:
  - Braille (open and closed)
  - Audio Daisy : CDs & Cassettes
  - Languages: English, Hindi, Tamil
  - In future: Training videos

Product Specifications Finalized

Device Specifications

- Sensor Specifications, Vibratory Output Specifications, White cane specifications, Power & Battery Specifications, Environmental specifications

Usability Requirements

- Ergonomics, Aesthetics, Biocompatibility, Buttons & Controls, Splash Proofing Requirements

Other Requirements

- Product Packaging Requirements, Product Training Requirements, Maintenance Requirements, Conformance to Accessibility Specifications,

CE Marking & Regulatory Requirements

- Conformance to Medical Device (Class I) meeting IEC 60601-1 Ed3.0, IEC 62304 Ed1.0, ISO 14971:2007, IEC 60601-1-2 Ed3.0, IEC 60601-1-6 Ed3.0, BS EN 2182:1999, BS EN 1985:1999, BS EN 60601-2-37:2001, IEC 60529, ISO 10993-10,

R&D Activities in Progress

- Material selection for components and product redesign for manufacturability and assembly
- Study of field of view for obstacle detection and studies pertaining to trade-off between obstacle detection and path planning
- Reliable mechanisms for direction adjustment of ultrasonic sensors
- Mechanisms for mounting and detachability of smart cane with white cane
- Study of vibration intensity, tactile patterns and their perceptibility
- Ease of learning, ease of training and ease of changeover issues
- Short-term and long-term adaptability issues of the product as associated training plan

Other Milestone Activities in Progress

Development of Field Deployable Version of Product

- Efforts have been initiated to redesign product from the point of view of manufacturability and to develop low cost tooling to produce field deployable version of Smart Cane

Planning and Design of Field Trials

- To undertake extensive field trials during III milestone period, planning and design of field trials with the help of experts has been initiated.

Product Testing Activities

- Building test facilities for various testing of product has been planned. Some of these tests would be outsourced.

CE Marking & Regulatory Requirements

- Procedure for CE marking process has been initiated.

Partnerships Established

- National
  - National Institute for the Visually Handicapped (NIVH), Dehradun
  - National Institute for the Visually Handicapped (NIVH), Haldia
  - National Institute for the Visually Handicapped (NIVH), Chennai
  - Blind Persons Association, Ahmedabad
  - Xavier's Resource Centre for the Visually Challenged (XRCVC), Mumbai
  - National Association for the Blind (NAB), Delhi
  - National Association for the Blind (NAB), Shimla
  - National Association for the Blind (NAB), Chitrakoot
  - Centre for Blind Women, Delhi
  - All India Institute of Medical Sciences (AIIMS), New Delhi
  - Worth Trust, Katpadi
- International
  - Royal National Institute of Blind People (RNIB), London & Peterborough, UK
  - Guide Dog Association, UK
- Participation in Networking Events
  - National Conference on Orientation &Mobility, NIVH, Haldia
  - National Conference on Mobility, Delhi [Nov 2011]
  - Tech Share India, Delhi [Feb 2012]

Expected Intellectual Property

Device – Elongated Design
- Improved & miniaturised electronics & PCB
- Ultra sonic Sensor, battery miniaturization
- Additional features like locators
- Vibration related improvements

Patents

Mechanical Design
- Handle design
- Angle adjustment
- Sensor mount on the cane

Design Registrations

Packaging design including labels

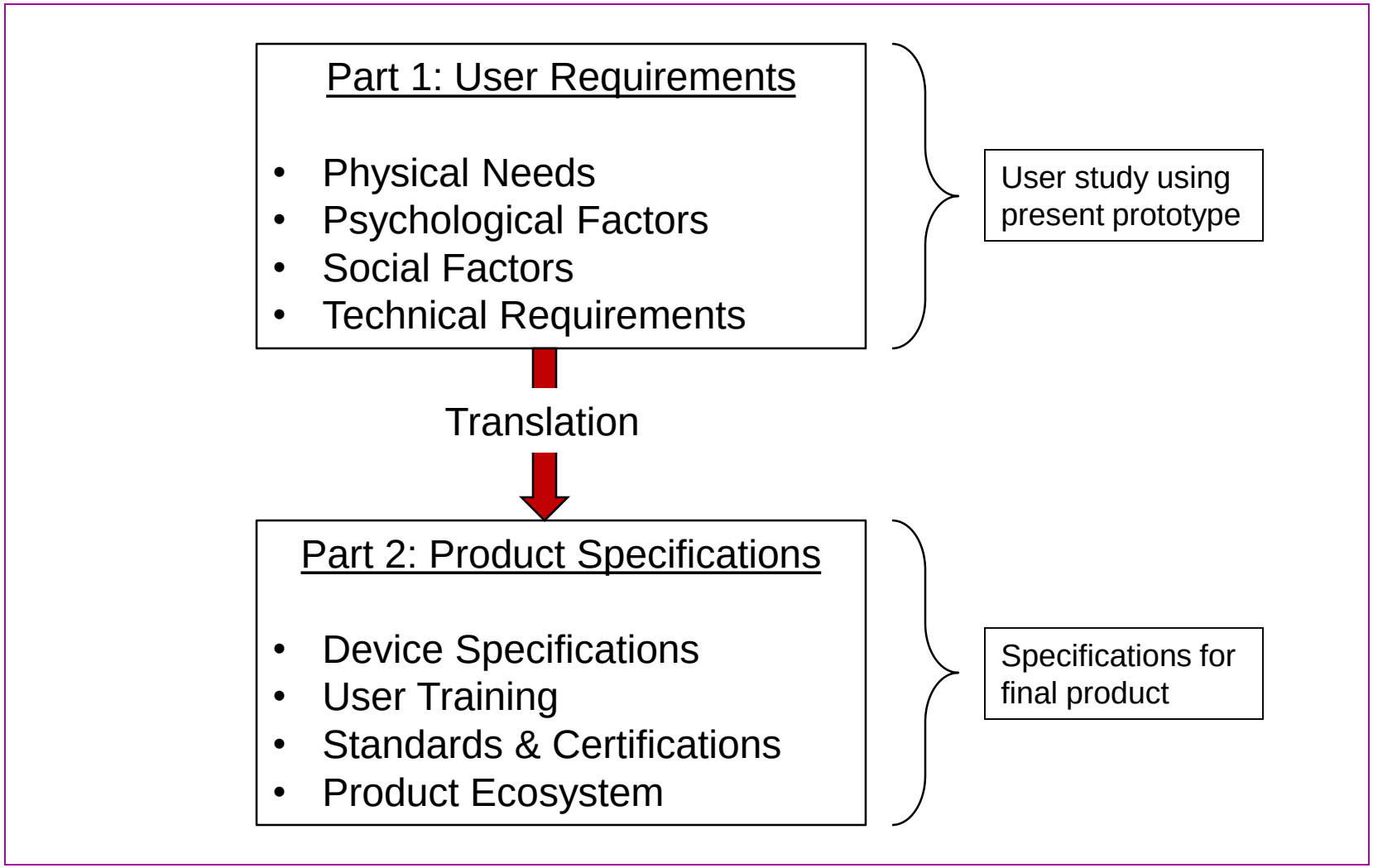
Training Material
- User self learning manual
- Training manual for sighted assistance
- Audio CD, Braille books, cassettes in multiple Indian languages
- Training techniques manual for mobility instructors

Copyrights

Translational Research Gap

Prototype (Rs. 10,000)	Usable Product (Rs. 2,000)
Research-grade electronics and design	Industry-grade electronics and manufacture-ready design.
Limited device testing in lab settings	Rigorous testing for standards and certifications (CE).
Limited feedback from a small group of users. Does not fully capture user variability.	Formal field trials at multiple sites with a varied user group in real-life scenarios.
Not much emphasis on manufacturability and maintainability of product	Design modifications based on field trials and setup for production.
Study restricted to product alone	Development of complete product ecosystem

Specification Refinement



Testing, Certification and Compliance

- Working with UL for CE marking
  - Technical files prepared and submitted for review
- RNIB, UK
  - Indpendent assessment under progress
- NIVH and NHSRC (Govt. of India bodies)
  - Assessment for inclusion in Govt. subsidy/grant schemes

Standards and Compliance

- Class B - IEC 60601-1-11 home health care standards
  - EN 1985
  - EN 12182
  - EN 60601-1: 3rd edition & EN 60601-1-2
  - EN ISO 14971:2012
  - EN 62304
  - EN 62366
  - EN 980 & EN 1041
- External Lab Tests
  - CISPR 11/EN 55011
  - IEC 61000-4-3
  - IEC 61000-4-2
  - IEC 61000-4-8
  - ISO 10993
  - IEC 60601-1 / 60529

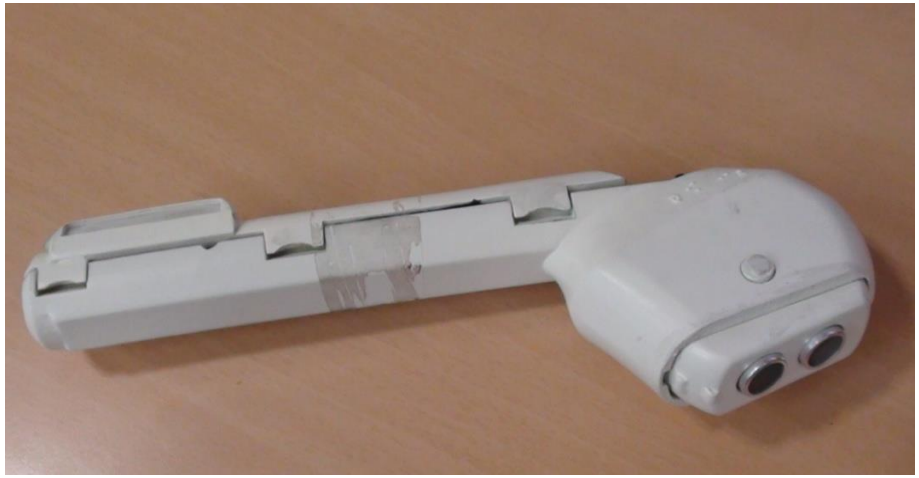
Consultation & Gap analysis by Underwriter Laboratories

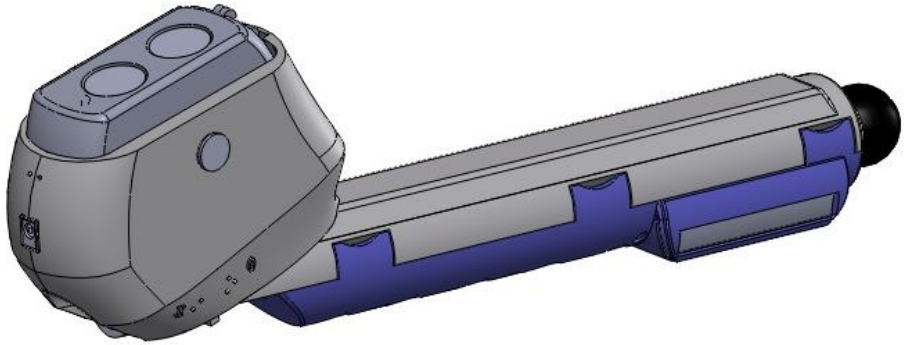
Training

A structured 4-step training protocol has been evolved

- Functionality in brief
- Orientation of external components and buttons (hand-over-hand technique)
- Learner holding the device and moving with a commentary from the trainer (walking-alongside-and-describing method)
- Learner moving independently with trainer observing

Smart Cane used for 30 user trials





Major Feedback Items from 30 user trials

- Reduced size
- Reduced weight
- Ease of use
- Better product controls
- Ergonomic grip
- Better perceptibility of vibratory patterns
- Aesthetics
- Portability

Validation Trials

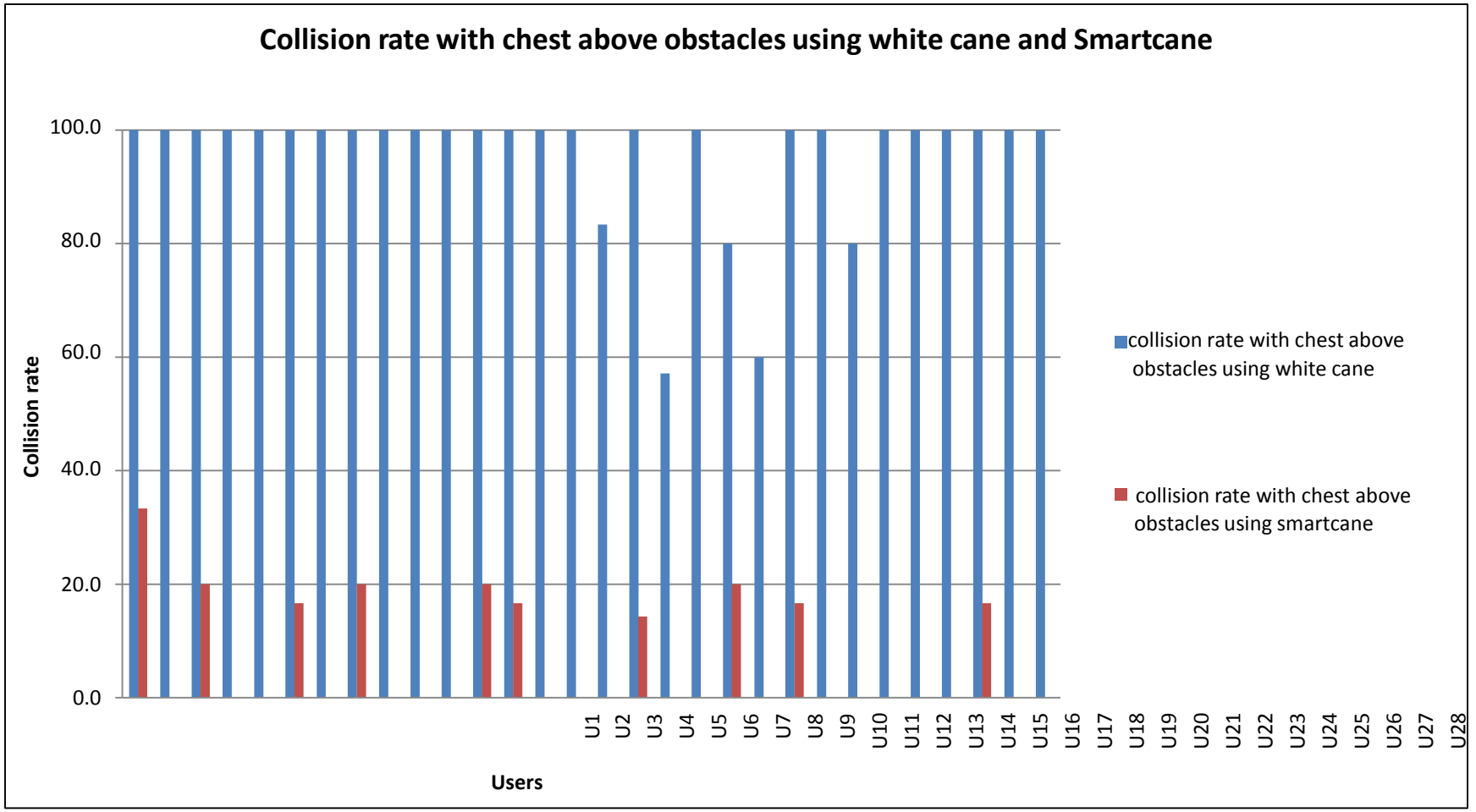
- An obstacle range at IIT Delhi: A 100m long, corridor-type obstacle-course with diverse obstacles e.g. hurdles, ladder, chairs, suspended plastic pipes, bicycle, protruding sign board etc.
  - The study aimed at quantifying number of obstacles detected, number of collisions and the distances of detection
  - 31 users went through the obstacle course and preliminary study results are included
- Field trials: 100+ users at 6 sites (Delhi, Dehradun, Mumbai Ahmedabad, Chennai, and Bangalore)
  From this we would analyze and include
  - A before-and-after quantitative observation-based study to assess improvement in obstacle detection
  - A before-and-after questionnaire-based study assessing the impact on independent mobility in natural mobility environments

User Study Sites

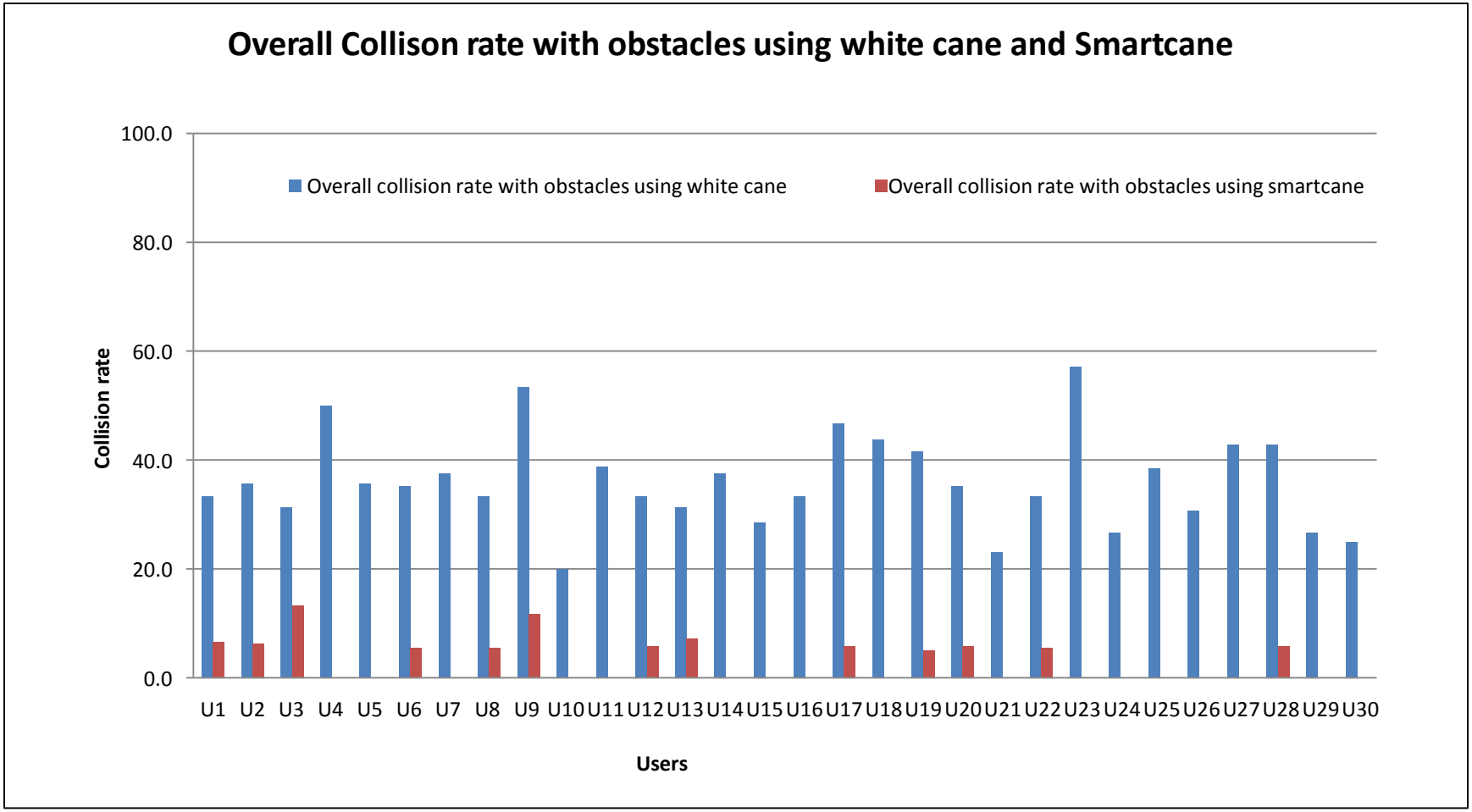
Smart Cane used for validation trials

Obstacle Course at IIT Delhi

Collision Study using Obstacle Course



Collision Study using Obstacle Course



Visuals from field validation trials

Saksham Trust, Delhi

Saksham Trust, Delhi

NIVH, Dehradun

XCVRX, Mumbai

Outreach Activities

- Demo in Techshare India Conference and 13th International Conference on Mobility and Transport for Elderly and Disabled Persons (TRANSED 2012)
- Held discussions with Smith-Kettlewell Eye Research Institute, Blind House, San Francisco, Biodesign programme, Stanford University
- New relationships/collaborations established with Arvind Eye Care, IAB, Madurai, Benetech/Bookshare, Palo Alto
- Many Invited lectures in Indian Institutes and Conferences
- Visits by UNICEF & Thoughworks/McKinsey
- Relationship established with Deafblind organizations such as I-partner and users.

Trials with Deaf blind User

Other Activities

- Planning for validation trials are in Progress
- Obstacle course design for mobility testing
- Planning for trainer’s training
- Working on product dissemination models
- Working on a web portal for the product
- R & D for incorporating additional user needs
- Smart cane compatibility with different white canes
- Feedback from children, elderly and from rural population

Trials with Elderly Blind Users

Thank You