Development of an Intelligent Robotic Rein for Haptic Interaction with Mobile Machines

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Development of an Intelligent Robotic Rein for Haptic Interaction with Mobile Machines

by

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The undersigned herby certify that they have read and recommend to the Faculty of arts, Computing Engineering and Science for acceptance a thesis entitled "**Development of an Intelligent Robotic Rein for Haptic Interaction with Mobile Machines'‘,** by Musstafa Elyounnss in partial fulfilment of requirements for degree of Doctor of philosophy.

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Publications

1- Elyounnss, M., Holloway, A., Penders, J., & Alboul, L. (2016, June). Development of an intelligent robotic rein for haptic control and interaction with mobile machines. In *Conference Towards Autonomous Robotic Systems* (pp. 111-115). Springer, Cham.

2- Elyounnss, M., Holloway, A., Penders, J., & Alboul, L. (2016). Development of an intelligent robotic rein for haptic control and interaction with mobile machines. In Proceedings of EUCognition 2016 - "Cognitive Robot Architectures" - CEUR-WS

Abstract

The haptic sense is often placed secondary when compared to vision and hearing in allowing navigation and autonomy. However, in certain conditions such as low or no visibility, the haptic senses can play a crucial role in aiding navigation and obtaining spatial knowledge of the environment and object properties. For example, search and rescue operations are often undertaken in complex and hazardous situations where factors such as limited or no visibility, noise and time constraints impede progress into an unknown environment. In these situations, the fire-fighter/rescue personnel could be aided by a machine (a mobile robot) that can sense and give the follower tactile and haptic information in a similar manner to the interaction between the visually impaired person and a guide dog. The visually impaired person follows the dog through the signs being transmitted to his hand and interprets them into information about the environment and how to navigate the route. The aim of this research is to investigate and build a prototype robotic rein to emulate the natural and adaptable relationship observed between a guide dog and human when traversing an unknown path. From the previous work, an investigation and evaluation of the design of the SHU prototype have been undertaken and its outcomes are used in this research to improve the new system prototypes, especially in the area of designing the feedback and adaptive control.

The new system has divided into four prototypes, each prototype has separated test to determine it is suitability. In the prototype (I) a set of sensors set in the front edge of the existing rein to know follower /robot location. The prototype (II), will implement to moving rein by installing an actuator. Prototype (III) has some sensors in the grip of the rein to calculate the strength of tensile which occur between the follower hand and the long axis of rein. In the prototype (IV), all previous prototypes will be connected to an integrated system which can move the follower to follow the robot path by sending messages from the robot to the follower in the form of rein movements

The resultant system is an intelligent robotic rein which continuously interacts with the user to optimize the guidance in terms of comfort, following accuracy and safety. The improved system has been tested, analysed and evaluated against previous designs and compared against the aspiration of the human - guide dog relationship.

A novel idea has been established in the use of the sensors to raise the level of the robot human interaction and achieving automatous robot/ follower safe navigation.

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Chapter one

INTRODUCTION

1.1-Background and concepts

Search and rescue operations are often undertaken in complex and hazardous situations where factors such as limited or no visibility, noise and time constraints impede progress into an unknown environment.

In such situations rescue individuals must often rely on haptic feedback for exploring the environment, assessing the risk and exiting safely. In recent years limited attention has been paid to this subject, especially to enhance communicational proficiency by using haptic sensors to preserve human life (Jones et al., 2013).

In these cases, humans cannot use some of their senses. For example, the fire-fighters cannot see the objects in front of them, nor can they listen to the sounds that occur near to them because of breathing instruments sounds. In such cases, it is necessary to look for the use of robots because of their capabilities using sensors. To provide adequate information about the environments and as a result of the lack of vision and hearing it is necessary for the robots to provide information about the environments in a tactile and haptic way as it exists in the blind man and the guide dog to get all the information about the path and surrounding environment, (Penders et al., 2011).

During the last three decades, several researches have introduced devices that use sensor technology (Ando et al., 2008) to solve such problems and improve the visually impaired follower’s mobility in terms of safety and speed, examples of these devices, collectively called Electronic Travel Aids (ETA). These ETA’s have not found wide use among them targeted user (Farcy et al.,2006), (Lara,2013), because of inherent limitations and cannot be used for obstacles at floor level, also most use audio feedback which has some disadvantages in the noisy environments such as busy public spaces (Brabyn, 1982). For these reasons the system design has primarily been dependant on the type of machine follower feedback and the feedback depends on the type of environment (Ulrich and Borenstein, 2001). For example; systems with audio feedback can be used in quiet areas and haptic feedback utilized for smoky/low visibility and noisy environments (Hayward and Maclean, 2007). In this research, there is a concentration for haptic and tactile feedback as a consequence of the proposed operational environment.

1.2-Problem definition

The fire-fighter/rescue personnel face numerous challenges while entering and exploring dangerous environments in low or no visibility conditions and often without meaningful auditory and visual feedback. In such situations, fire-fighters may have to rely solely on their own immediate haptic feedback in order to make their way in and out of a burning building by running their hand along the wall as a mean of navigation (Betz and Wulf,2014). Figure (1.1) shows an example scenario where fire-fighters rely on their haptic feedback to explore an unknown environment. Consequently, the development of technology and machinery (robot) to support exploration and aid navigation would provide a significant benefit to the search and rescue operation; enhancing the capabilities of the fire and rescue personal and increasing their ability to exit safely (Jones et al., 2013).

Figure (1.1) Fire-fighters when relying solely on their haptic feedback (adapted from, Ghosh et al., 2014)

This research will investigate how to design a haptic robotic hard rein, inspired by the previous studies of the communication between people with impaired visibility/blind and guide dogs. In the human guide dog case of a partnership, there is a symbiotic relationship between a person and dog which often develops. This is based on mutual trust and confidence which the robot must strive to emulate. Many blind and partially sighted people have developed highly effective navigation and exploratory partnership with their special trained guide dogs. When walking along the street to the destination, the visually impaired person is linked directly to the guide dog via a stiff interface known as a handle attached to a harness on the back and shoulders of the dog as shown in figure (1.2). This simple device is the main conductor for necessary reciprocal haptic feedback between the partners. The handlers feel the dog movement and direction while the dog monitors the handlers walking and proceed together; this mutual understanding is a prerequisite for successful task performance (McKnight and Chervany, 1996).

Figure (1.2) Blind person with his guide dog (adapted from, guidedogs.blogspot.com)

Inspired by this, a mobile robot hard rein will be designed and implemented with the aim to solve the problem of navigation; the design must consider a transparent technology from the side of the familiarity and ease of use, as typical firefighting /rescue situations are time critical and require immediate responses.

1.3-Aim and objectives

The aim of the research is to investigate and build a prototype robotic hard rein to emulate the natural and adaptable control relationship observed between a guide dog and follower with the following objectives:

1-Literature review of existing work and writing in this felid

2-Evaluation of existing SHU design and extract headline, parameter& constraints

3- Redesign the rein in multi stage prototypes.

4- Integration of the stage prototypes.

1.4-Thesis structure

Chapter 2 of this thesis explores the existing literature in the field to provide an overview of existing work and an overview of existing guidelines and identifying where further work is needed. Chapter 3 details a range of preliminary tests done on a previous design to establish baseline parameters and constraints for the new prototype. Furthermore, it proposes and examines different designs to solve the defined problem and explore which ones were the most effective to delivering haptic information between follower and robot. Chapter 4 describes the implementation and design of stage prototype (I) (sensor only system) in this part of the research sensors have been placed at specific joints/axes of the rein to collect data about robot/follower position. Chapter 5 introduces and explains stage prototype (II) which focuses on the motion feedback system, in this prototype the actuator with its sensor placed on the rotational joint allow the rein to provide variable force on the follower's forearm guiding/steering the follower in the desired trajectory. Chapter 6 describes stage prototype (III), which focuses in tensile force sensing system, in this prototype sensors placed on the rein grip allows to measure the tensile strength happening between the follower's hand and the rein and provide signals to control the rein movements; these movements proportional to the value of tensile strength produced between follower arm and rein axis when the robot turns. Chapter 7 describes and explains stage prototype (IV), this prototype is an integration of stage prototypes (I), (II) and (III) and implements a shared control system to achieve the main target of research and enable the follower accurately, safely and intuitively to the path of the robot guide. Chapter 8 summarises, discusses and explores the contributions of this work, also providing logical conclusions of the thesis and indicates future work.

Chapter two

LITERATURE REVIEW

2.1-Introduction

The purpose of this literature review is to provide the reader with a general overview of the haptic sense and give the reader a view of a fruitful area for research. Recently, this concept has become a popular subject in human interaction science. The first part of this chapter gives a brief description of haptic sense, roles of human hand in haptics, human-robot interaction, trusting in autonomy systems and rescue robots. Finally, it gives a brief idea on the reins project including current work and designs

2.2-The haptic sense

The term “haptics” was proposed by Revesz 1950, after observing blind performance and referring to an unconventional method of experience rather than traditional methods of touch and kinesthesis. More specifically, this term means "active touch" rather than passive touching (Srinivasan, 1995). Gibson emphasizes active touch as an exploratory concept rather than merely a receptive sense. From this perspective, the “hand is a kind of sense organ as distinguished from the skin of hand” (Gibson 1962, pp.477-491).

In psychology and physiology experiments, the haptic denotes to the human ability to understand the surroundings through active exploration (Heller,2013), typically with hands, as when touching an object to estimate its shape and material properties, which is usually called haptic touch (Gibson, 1962).

Finally, the haptic sense is crucial to the normal functioning of a human at different levels, from controlling the body to the perception of the environment, as well as learning and interacting with it.

There is currently strong psychological attention to the cognitive dimension of tactile sensing in general and to the development of a tactile ability in blind and visually impaired children (Jones et al., 2013).

2.3-Roles of the human hand in haptics

When developing haptic interfaces the contact points with the human are of critical importance and determine the design parameters for the system. In this research where an intelligent haptic rein is designed for interactions with the human hand/arm, it is necessary to know the basic structure and roles played by the human hand in haptic sensing (degrees of freedom, the range of movement and force/resistance of movement), (Oscari et al.,2016). The mechanical structure of the human hand consists of 19 bones linked by many low friction joints and protected by soft tissues and skin. The bones are connected to approximately 40 muscles through many tendons which serve to initiate 22 degrees of freedom of the hand (Srinivasan, 1995). The sensory organization includes large numbers of different kind of receptors and nerve endings in the skin, joints, tendons, and muscles. Appropriate mechanical, thermal or chemical stimuli activate these receptors, causing them to convey electrical impulses through the neural network to the central nervous system, which sends commands through the different neurons to the muscles for desired motor (muscle) action (Srinivasan, 1995). "In any action involving physical contact with an object, for exploration or manipulation, the surface and volumetric physical properties of the skin tissues do important function in its successful performance. For example, the finger pad, which is used by primates in almost all precision functions, consists of ridged skin (about 1 mm thick) that encloses soft tissues composed of fat in a semi-liquid state", (Srinivasan 1995, pp. 162-164). As a material, the finger pad shows complex mechanical behavior such as inhomogeneity, anisotropy, rate and time-dependence (Louis and Buell, 2003). "The compliance and frictional properties of the skin together with the sensory and muscle capabilities of the hand allow gliding over a surface to be explored without losing contact, as well as stably grasping smooth objects to be manipulated" (Srinivasan 2002, pp. 162-164). The mechanical loading on the skin and the transmission of the mechanical signals through the skin are all strongly dependent on the mechanical properties of the skin and subcutaneous tissues (Pawlaczyk et al.,2013). Tactual sensory information carried to the brain from the hand in contact with an object can be divided into two classes (Biggs and Srinivasan, 2002):

(I) *Tactile information*, which refers to the contact with the object sense and nature, mediated by the reactions of low threshold mechanoreceptors innervating within and around the contact area.

(II) *kinesthetic information*, refers to the sense of location and motion of limbs along with the allied forces, carried by the sensory receptors in the skin around the joints, mutual capsules and muscles, both with neural signals derived from motor commands.

2.4-Definition of autonomous

An automatic system can be defined as a system which will do exactly as programmed before, it has no option (Houghton Mifflin 2007). Whilst an autonomous system has many selections to make actions, i.e., an autonomous system has open self-control and can choose how to deal with the recent situation without human interaction. Also, in robotics, autonomy is defined by *the independence of human outside interaction* (Vasica and Billardm, 2013), which means the robot itself has full control (Stormont, 2014). Therefore an autonomous robot is a robot that makes actions with a high degree of freedom, which is particularly common in the field such as space searching, cleaning floors, delivering goods and services where there are huge amounts of uncertainty in the environment, and pre-programming for all cases is not possible (Stormont, 2014).

In some factories, robots are “autonomous” within the strict margins of their environment (Fullam, 2007a) it may not be that a high degree of autonomy exists in their environment, but the robot's workplace is often challenging, because of presence of many unexpected variables Such as the exact position of the next object of work and nature (size, type .etc.) of the object body. Autonomy can be classified into a number of levels (Stormont, 2014), (Boessenkool et al., 2013):

1- Direct interaction mode: Which is used for haptic or tele-operated devices, and the human has nearly complete control over the robot's actions.

2- Operator-assist modes: Operators have the commanding medium-to-high-level tasks, with the robot automatically figuring out the low-level tasks.

3. High-level autonomy: where the robot may move without human interaction for periods of time. Higher levels of autonomy do not necessarily need additional complex cognitive capabilities. For example, robots in assembly plants are completely autonomous but operate on a fixed path.

2.5-Human-Robot Interaction (HRI)

Human-robot interaction was established before any robots existed, in both academic speculation and science fiction. Because HRI depends on human communication, many facets of HRI are continuations of human communications subjects that are much older than the presence of robotics. (Sauppe and Bilge, 2015), (Sheridan,2016).

Author Isaac Asimov writes the three laws which manage the collaboration between human and robots, these laws mentioned as follows:

1- A robot may not injure a human being or, through inaction, allow a human being to come to harm.

2- A robot must obey any orders given to it by human beings, except where such orders would conflict with the first law

3- A robot must protect its own existence as long as such protection does not conflict with the first or second law

These three laws attempt to capture the idea of harmless contact between human and robot (Thomas et al.,2016). This importance of the intricate relationship arises when humans and robots work closer to each other; danger for the human usually increases. In many examples, this issue has been mitigated by not permitting humans and robots to share the same workspace at any one time. This is realized by defining distinct zones using physical barriers. Thus, the presence of humans is totally banned in the robot workspace while it is working (Rybski et al., 2012), (Kopacek and Hersh,2015).

With the growth of artificial intelligence, the autonomous robot could have more proactive behaviours when planning its actions in complex environments. These new capabilities must keep safety as the first priority. To allow this generation of robot, research is conducted on human detection, movement planning, place reconstruction, intelligent behaviour through task planning and compliant behaviour using force control (impedance or admittance control schemes) (Dautenhahn, 2007).

Many HRI studies have the interest of developing models of human's prospects regarding robot interaction by design and algorithmic developments that would give more habitual interaction between humans and robots. HRI researches start from how humans work with unmanned vehicles to peer-to-peer collaboration with robots. In recent years many people in this field are undertaking studies that attempt to explain how humans collaborate and interact with robots (Dautenhahn, 2007).

2.6-Trust and autonomous systems

Autonomous robots are robots which can do desired tasks in new environments without continuous human control (Stromont, 2014). The significant aspect is that an autonomous robot can work in unstructured environments to performing necessary tasks, without the need for human involvement on a steady basis. Usually, autonomy falls in a wide spectrum; extending from no autonomy (tele operator system) to full autonomy systems which require no human interference. Problems can however rise with fully autonomous systems which work without any human interference as the problems of responsibility, accountability and obligation become prominent when errors and or accidents happen. This consequently can lead to arguments about what is the level of autonomous can be trusted and accepted (Stromont, 2014), (Ososky et al.,2013).

Trust has been defined in 1988 by Diego Gambetta and we can take his definition for trust as a starting point "*trust is a particular level of the subjective probability with which an agent assesses that another agent or group of agents will perform a particular action, both before he can monitor such action (or independently of his capacity ever to be able to monitor it) and in a context in which it affects his own action*". Some persons think that when they trust somebody, they indirectly mean that the probability that he will do an action that is beneficial or at least not detrimental to them is highly sufficient for them to consider engaging in some form of cooperation with him and this also can define trust in general (Stromont, 2014).

Autonomous systems in most instances still viewed with a lack of trust. This is evident in regulatory guidance. For example, United States Federal Aviation Administration does not permit the operation of unmanned aerial vehicles in the national airspace (Lazarski, 2001) The recent developments in driverless vehicles on public highways has been given significant coverage by researchers, regulatory bodies and media exemplifying, the issues of robots interacting with followers (Lazarski, 2001).

An additional cause for the lack of trust is the ethical consequences when erroneous actions happen (responsibility of whom). From the previous literature on the trust of autonomous systems, it is clear that there is no widespread agreement on the factors that contribute to human trust in robots particularly in dangerous environments (Lazarski, 2001), (Wagner, 2014).

2.7-Search and rescue robot

Robots with some sensing capabilities are appropriate to use in dangerous or hazardous places. This can be attributed to their sensing capabilities and consequent ability to manoeuvre in low visibility environments such as smoke, physical size, and shape which may allow access to narrow/small areas and ability to operate in hazardous/toxic environments. Robots have been used to successfully and safely explore sites such as the Chernobyl atomic plant after the disaster 1986 (Penders, 2014) (Petryna,2013) and Fukushima Daiichi Nuclear Power Plants 2011 (Nagatanim,2013). Robots are also used in crises such as earthquakes and volcanoes, mainly when searching for victims under debris, rubble and from small cracks where human beings are simply unable to explore (Penders, 2014). For example, in the 9/11

World Trade Centre (WTC) disaster, Mobile robots of diverse sizes and abilities were deployed (Snyder et al., 2001). A problem however is the extreme terrain, with a different mass of rubble etc., which obstruct the robot's movements, figure (2.1) shows robot deployed after a disaster. Search and rescue robots are generally remotely controlled; one hurdle when remotely guiding a robot that is not directly visible because of the direct line of sight (this mean sometimes the robot disappears and it is hard to control).

Figure (2.1) Robots after the disaster (adapted from / bing.com)

It is important to note that dogs are also used for such searches and they could be equipped with cameras and other devices to enable remote observation. It must also be noted that dogs have much better manoeuvrability and are more intelligent than the robots currently used; however the working time length for a dog is quite short and they are vulnerable to hazardous materials (Penders, 2014). Figure (2.2) shows rescue dog with some navigation tools.

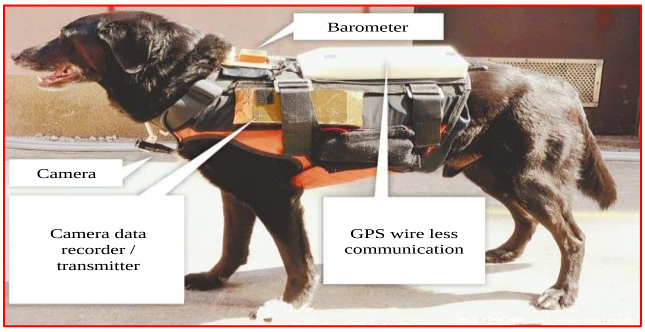


Figure (2.2) Rescue dog with navigation equipment's (adapted from, bing.com)

The EU project Guardians established a number of autonomous robots to support the firefighters and rescue workers in smoky, dusty and noisy regions. Such sites are often risky and exhausting and even well-trained skilled firefighters could get confused, disorientated and potentially lost, which could have serious consequences (Penders, 2014).

2.8-Haptic feedback to improve operator’s perception

Mobile robots are ordinarily used in the exploration of unknown and dangerous environments. Mine removal and underwater exploration are common applications carried out by mobile robots (Lin. and Kuo, 1997), (Pacchierotti et al.,2014). Robot movement is usually controlled by system operators with the help of a camera attached to the robot to inspect the area from above. However, although visualization systems give much information of the region, they need network bandwidth and significant attention from the operator. To reduce this problem, haptic devices have been recently provided in the field of robotics as a way of improving the operator’s perception (Smith et al., 1992). They provide operators with an extra sense of “feeling” the robot area, thus making it easier to keep away from obstacles and reducing the number of collisions. However, the direct force providing method yields a problem about necessary navigation time. This extra sense often adds the amount of information for operators to interpret and consequently leads to an increase in the navigation time (Nikos et al., 2006).

2.9-Reins project

The design and investigation of haptic interfaces (reins) between a human agent and a mobile robot guide is the first aim of the rein project. The reins will facilitate joint navigation and inspection of a space under conditions of low visibility, as a consequence of dust and smoke which normally are observed in search and rescue applications. The focus is therefore on haptic and tactile human-robot cooperation. Also, it has been found that a limited visual field and obscured cameras add to the distress of humans working under stress. The Reins project aims to explore the communicational landscape in which humans with low/impaired visibility may work with robots with a particular focus on tactile and haptic interaction.

The reins project utilizes a mobile robot which leads the human for navigation in risky areas (rescue areas). The robot offers rich sensory data and is enabled to try the mechanical impedance of the objects it comes across. A number of rein based feedback systems were implemented: a soft rein (rope), a wireless rein and a stiff rein (inspired by the lead for guide dog) enabling the human to use the robot to actively probe objects.

The reins project thus builds the means to discover the haptic human/robot interaction abilities. A research question which has risen from the project is whether the *information should be explicitly encoded as messages or can remain implicit*. In this phase of the reins project, the robot was adjusted to give rich feedback data to the human.

Specific objectives of the REINS project (London college, 2015) :

1- To understand how human participants can learn to associate a pattern sent from a robot (*feedback*) via a soft/hard/wireless rein with a given message under different levels of distraction.

3- To understand how a robot could learn to interpret messages encoded by a human (*control*) under different levels of distraction.

The work in the proposed PhD programme builds on research and technologies explored within the REINS project with a specific focus on how a fixed rein can give intuitive and clear guidance. Also, it presents way of human-robot interaction in which one person with limited visual perception of the environment (a follower) is guided by a robot with some capabilities (a guider) such as explore and obstacle detection in dark and dusty environments, by using ultrasonic and infrared sensors. Moreover it has high degree of accuracy. Also this PhD will investigate how to design this haptic robotic rein, inspired by the previous studies of the communication between people with impaired visibility/blind and guide dogs. Figure (2.3) shows a comparison between environments of a visually impaired persons and a firefighter where just haptic sense can be used. This research uses electric components to achieve the mentioned above idea and convert the current mechanical system structure to electromechanical system structure

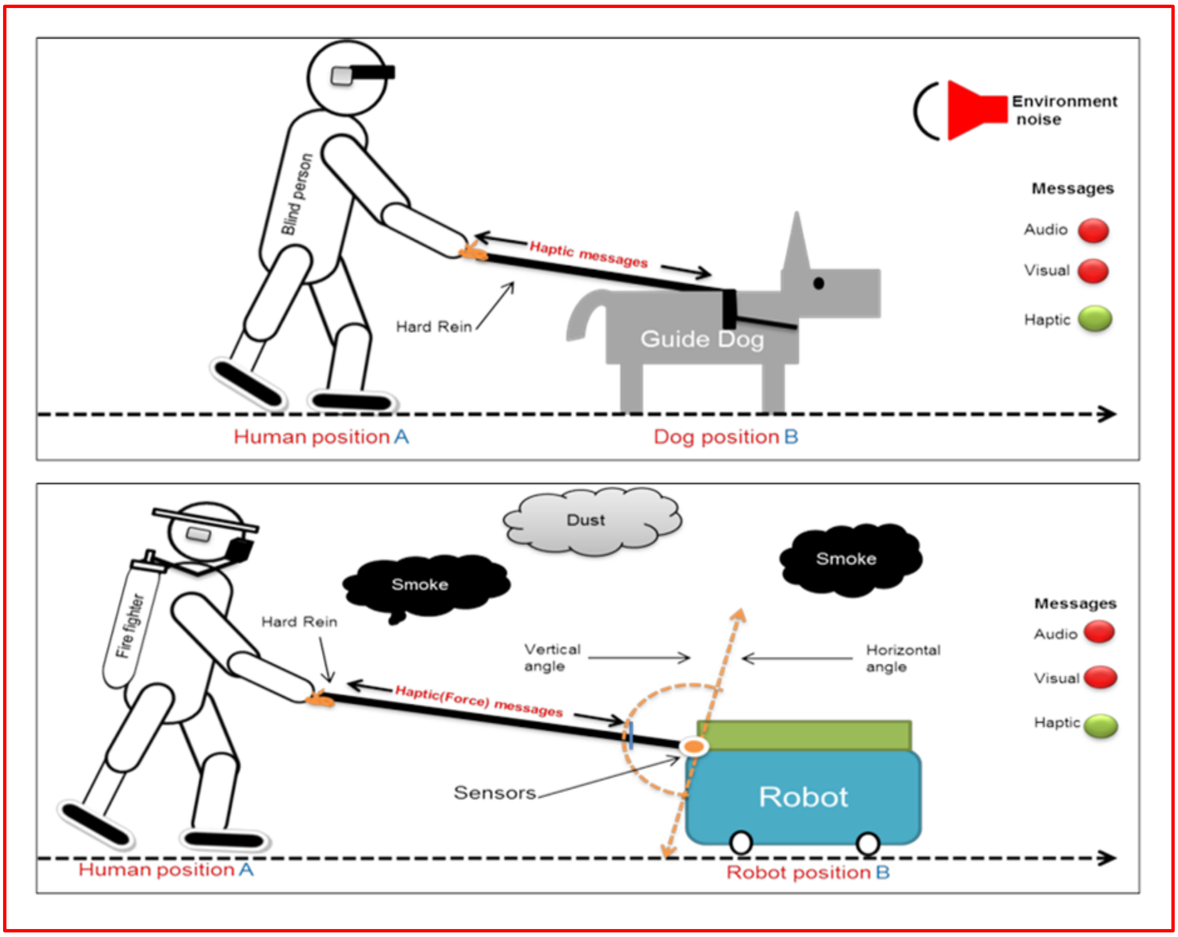


Figure (2.3) Comparison between environments of a visually impaired and a firefighter

2.10-Investigation and evaluation of the current designs

A comprehensive investigation of previous and existing technologies/designs used in similar applications has been undertaken. Some examples are targeted to specific application areas such as fire and rescue; however in most cases, the major end followers are visually impaired and or/mobility impaired persons.

A proposed solution is the electronic guide cane which has been aimed to help visually impaired people to avoiding obstacles and risks using a number of ultrasonic sensors which can discover obstacles and consequently steer the follower around it, the steering action results in a very noticeable force felt in the hand (Ulrich and Borenstein, 2001). Many researchers have proposed similar devices that use sensor technology to improve the blind followers experience. Where most suffer from the following three important defects (Shoval et al., 2000):

1-The follower needs to scan the surroundings actively to notice the obstacles (no scanning is wanted with the sonic guide, but it does not detect obstacles at floor level). This procedure is time-consuming and needs the follower's constant activity and conscious effort.

2-The follower must make additional measurements when obstacle is detected in order to determine the dimension and the object figure. The follower must then plan a route around the obstacle. Again, it is time-consuming and walking speed reduces.

3-Another problem with all devices that are based on audio feedback is interference with sound cues from the environment, which reduce the blind person's ability to catch these essential cues.

Moreover, to avoid these issues in applying mobile robot obstacle technology, other assistive devices for the disabled are conducted and developed, such as Nav Belt. Nav Belt consists of a belt, a portable computer, and an array of ultrasonic sensors attached on the front of the belt. In an experimental prototype shown in figure (2.4), the follower wears a portable computer as a backpack. Eight ultrasonic sensors, each covering a sector of 15^o are attached on the front pack, providing a total scan of 120^o. Although the Nav Belt successfully eliminated some of the problems common to conventional devices, the device lacked odometer capabilities and required a considerable conscious effort for the follower to comprehend audio cues (Shova et al., 1998).

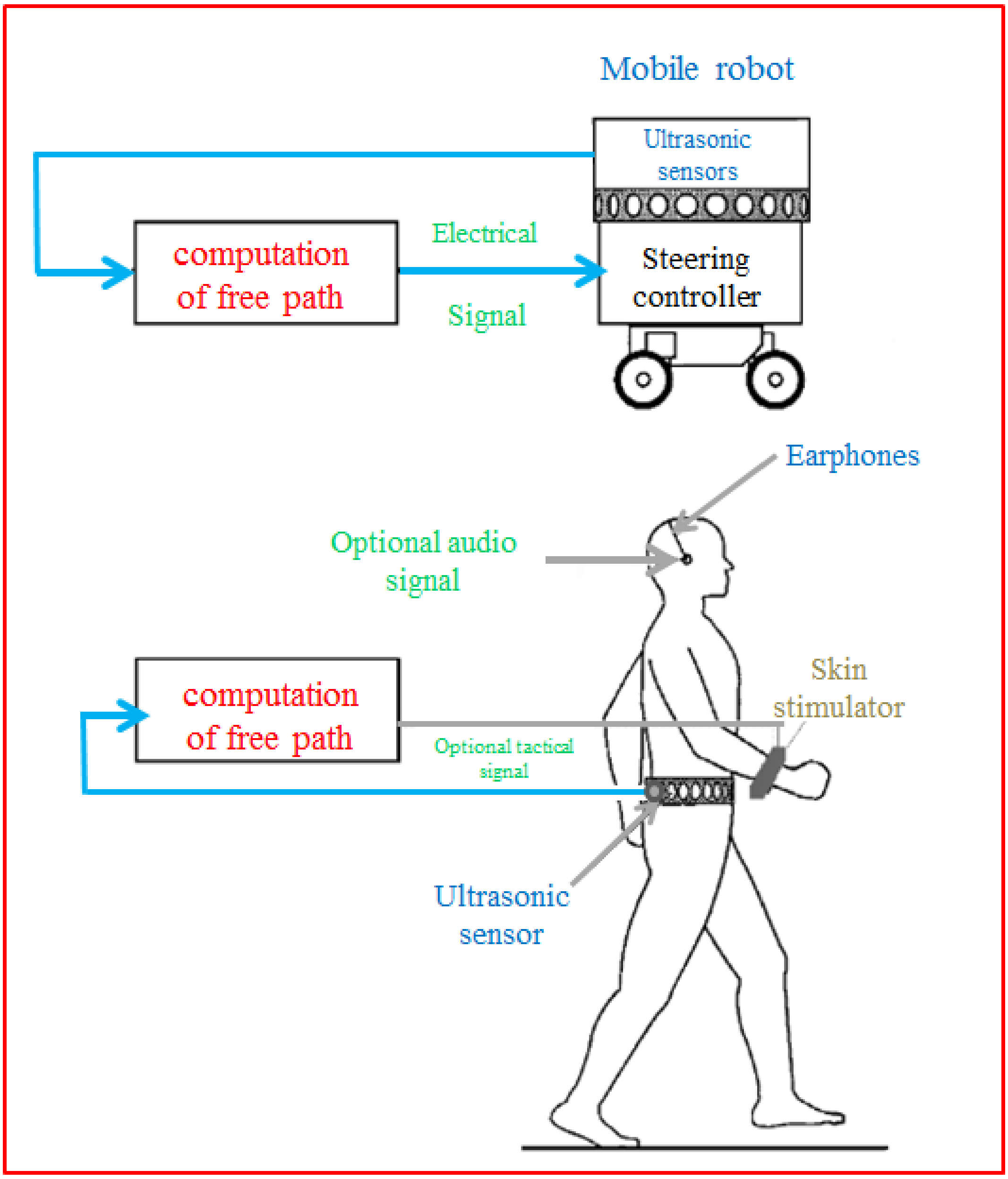


Figure (2.4) Nav Belt experimental porotype (adapted from, Shova et al., 1998)

A number of the proposed solutions share much in common with the traditional white cane and appear to be an evolution of the major concept, where the follower holds the Guide Cane in front of himself while walking in the proposed direction of travel. The guide cane as implemented by

University of Michigan's mobile robotics laboratory is considerably heavier than the white cane but rolls on passive wheels that support the weight through regular operation, both wheels are equipped with encoders to determine the relative motion. A servomotor controlled by the built-in computer can steer the wheels sideways left or right to avoid the obstacles. The cane is equipped with eight ultrasonic sensors that are located in the front in semi-circle fashion with an angular spacing 15°, thereby covering a 120° sector ahead of Guide can. The last two sensors face directly sideways and are mainly useful for following walls and for going through narrow openings, such as doorways. Moreover, it has mini joysticks situated at the handle which permits the follower to identify a desired direction/motion as shown in figure (2.5), (Ulrich1 and Borenstein, 2001).

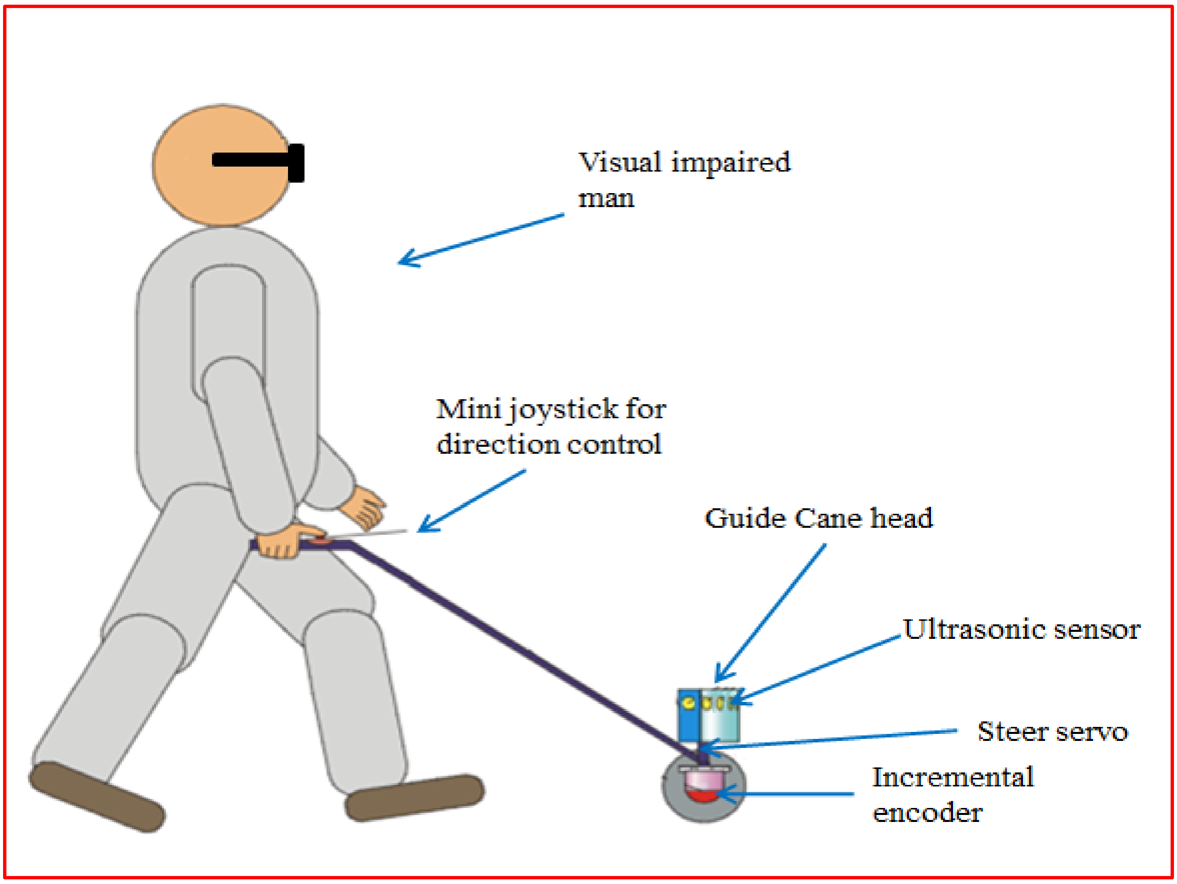


Figure (2.5) Construction of guide cane (adapted from, Ulrich1 and Borenstein, 2001)

Several improvements to the guide cane were implemented in later versions. For example, the number of sensors was increased to 10 ultrasonic sonars to cover a wider area front of the cane. Moreover, the system was equipped with brakes for the wheels in order to control the speed if required. In general systems such as the guide cane take care of local navigation task, allowing the follower to completely focus on the global navigation task, figure (2.6) shows the guide cane prototype.

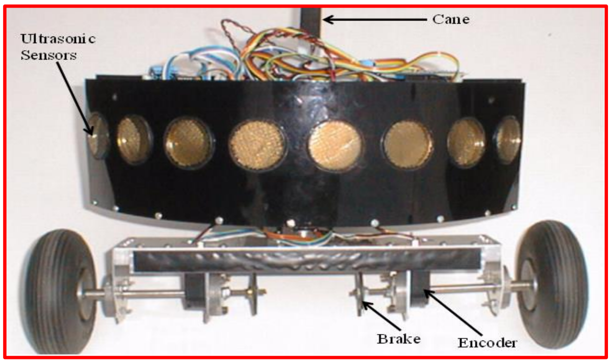


Figure (2.6) Guide cane prototype structure (adapted from, Ulrich1and Borenstein, 2001)

2.10.1-Robot walker

In this section, the robot walker will be described, which has been designed as an assistive device for the elderly/physically weak and /or persons with cognitive impairment to live independently or in senior assisted living facilities. In such cases, it has been noted that locomotion is most often the primary form of use and forms a serious requirement for health and wellbeing of the individual (Morris et al, 2003).

In previous walkers, the focus has been on safety but in the following application in addition to safety and navigational the stability of the follower is considered. The additional capabilities are achieved by a suite of software for localization and navigation combined with a *shared-control haptic interface* (Morris et al., 2003).

Such applications depend on a novel method to address both mobility needs of the elderly and the service needs of the nursing staff by joining the stability of conventional walkers with the sensing, planning and navigational abilities of mobile robotics. A solution to this has been offered by (Morris et al., 2003). The mobile robot is equipped with two force-sensing handle bars that resemble the grippers of conventional walkers. Forces asserted through this haptic interface are mediated with control from the navigation system in this way, or a method that maximizes a person's perceived freedom while still doing point to point navigation. This navigation system adds probabilistic procedures for mapping, localization, path planning, and collision avoidance. Mixed modes of follower help in the form of controlled robot motion and visual cues are examined to assist follower navigation without becoming disturbing to the follower's wishes. This mobile robotic platform is implemented as a *shared control system* (Morris et al., 2003). The shared control interface does however add a considerable layer of complexity, but it is a critical element in the development of an intuitive robotic walker. The robot must be capable of providing navigation and guidance while keeping a natural and predictable motion response. The shared control describes *a system where two or more independent control systems function concurrently to achieve common goal*s (Wasson and Gunderson, 2001). A comprehensive explanation of the shared control system can be concluded from the operation modes:

***Passive mode*:** in this mode, the robot main function is to avoid collisions with obstacles and monitor follower location and allow the follower to move freely.

***Active mode*:** in this mode, the desired system path is the same as the robots indented path and if the follower estimate path has deviation when compared with the desired path the robot motion will be reduced unless the follower realigns with the path. This mode of operation is accompanied by a graphical interface to help the follower to stay on the path.

Forced mode: in this mode, the robot path is used completely, and follower input is used as a means of switching robot motion on /off and must know that the follower has no control of direction and must keep strictly to the path.

Can say this can be used as a prototype platform for a robotics walker, which is suitable to escort nursing home residents and enabling great social interaction. In order to determine the best compromise between follower *freedom* and *finishing* a specified *navigation* task there is elderly Personal Aid for Mobility and Monitoring (PAMM). This system aims to support elderly people to live independently and providing physical help and guidance (Yu et al., 2003). This section clarifies it in two levels one is for an admittance-based mobility controller which offers a natural human-machine interface. The second is an adaptive *shared controller* which shares control between the *follower* and the *computer* based on metrics of follower performance, figure (2.7) shows the PAMM system structure.

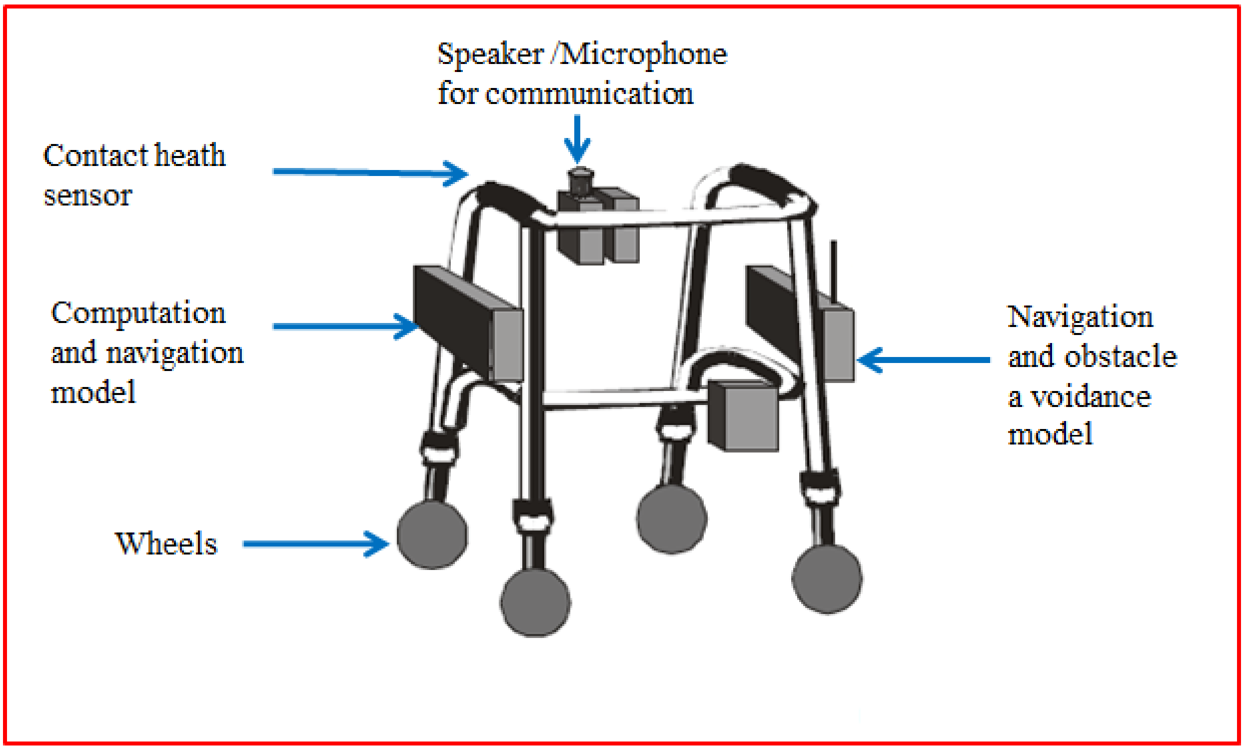


Figure (2.7) PAMM system structure (adapted from, Yu et al., 2003)

In such surroundings, a range of challenges exist. The main challenge of the control system development is how to allocate the control system between the follower and machine. The shared control system (which was described in the previous section) integrates the best capabilities of both the human and the machine. The human is best at high-level cognitive tasks like object identification, error handling and use of common sense in the existence of uncertainty; conversely, the machine has high mechanical and computational power and good accuracy. Many researchers are developing a number of strategies for the shared control system (Yu, 2000).

This interface determines the intent of the follower even in the occurrence of the follower's confusion. The controller provides to the follower as much control as possible, but it ensures follower safety by adjusting the control authority based on the demonstrated performance of the follower (Yu, 2000). It must be noted that the development and assessment of the control system of PAMM devices depend on experimental work carried out with the elderly in the eldercare centres (Yu, 2000).

2.10.2-Adaptive shared control in PAMM

The following section briefly discusses adaptive shared control in PAMM (personal aid for mobility and health monitoring) as described byYu. Adaptive shared control has a similar structure to that of a traditional adaptive controller. The system has a planner that creates an ideal path based on the mission and its knowledge of the environment. PAMM can determine its location in the environment by identification of signposts with a CCD camera. The computer controller produces a virtual force input based on the pre-planned and actual trajectory. The follower gives input to the system through force/torque sensors. The two control inputs to the shared controller have an associated gain. These gains reflect the authority of computer and human. These gains are changed by the adaptation law which calculates a performance index (measure how follower is performing) and adjusts the two gains. The output of the shared controller is fed to an admittance-based control which produces commands to the system (Yu et al., 2003). Finally, the PAMM system achieves the two main essential features, the human-machine interaction control and adaptive shared control. Figure (2.8) shows the PAMM working mechanism.

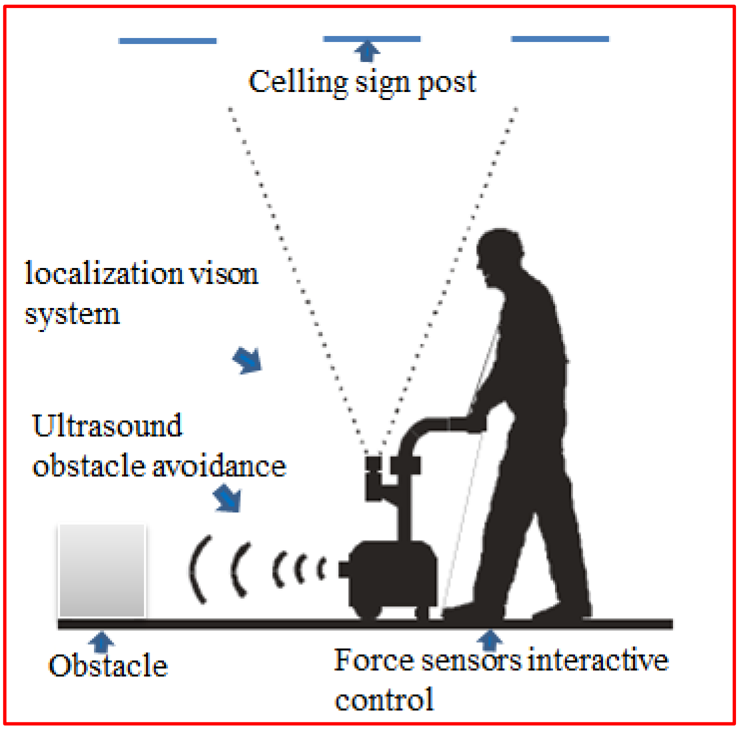


Figure (2.8) PAMM system mechanism (adapted from, Yu et al., 2003)

2.10.3-Sheffield Hallam robotics group work

This section discusses some of the work produced by the robotics group at Sheffield Hallam University, and specifically within the REINS project. This concentrates on firefighting and rescue applications where limited or no visual sensory information can be used and the predominant feedback method is using haptic interfaces.

The initial project proposed the design and evaluation of a haptic interface to enable a human to follow a robot under non visibility. The project assumed that the rescue operation was undertaken with the following constraints; *the ground is relatively passable* and *the main problem is dust and noise* (Ghosh et al., 2014). In this condition, there is a high possibility for a human firefighter to lose his route. Therefore, the fire/rescue personnel can be considered as being significantly visually impaired/blind.

In these situations, the proposed strategy of following a robot is promising but it also has many challenges. In particular, the communication between the robot and human to adjust *speed* and *direction* and the *type of codes/format* used to convey this information as only haptic communication is considered.

However, having a robot lead a person raises considerable problems, regarding to the degree of robot autonomy. To judge, the handler must know the difference between *locomotion* which means movement from point to point in the path and *navigation* which decided the start and end point of the journey. Additionally, it is necessary to know some factors such as the *path* of the robot which the human must follow, the *interface* used, what is the connection between the human and robot; this could be *wireles*s, a *loose rope* or a *hard-stiff* rein. In the case of a loose rope, it is not possible to indicate the direction, this problem is further complex in case of wireless connection, and the human and robot have no direct method of determining their location and orientation with respect to each other. However, with a stiff interface all these problems can be reduced and/or avoided.

A description of the stiff rein which was used in some experiments of human-robot following the stiff rein prototype was assembled from crutch- like handle with a joint at the base-connecting the pole to the robot. This consisted of a ball joint mechanism to allow free movement in all directions (Ghosh et al., 2014).

This prototype has a challenge to follow the robot, because of full freedom in the horizontal axis which causes the follower to lose track and forces to add springs. This spring system permits rotation of the handle in the horizontal direction. When the handle is aligned in the robot centre line, the springs have no tension, and when the handle is being rotated the spring system makes some tension on the handle, this tension increases with the increase of rotation angle, also this prototype comes with a pin enabling to nullify the action of the spring, figure (2.9) shows a spring system.

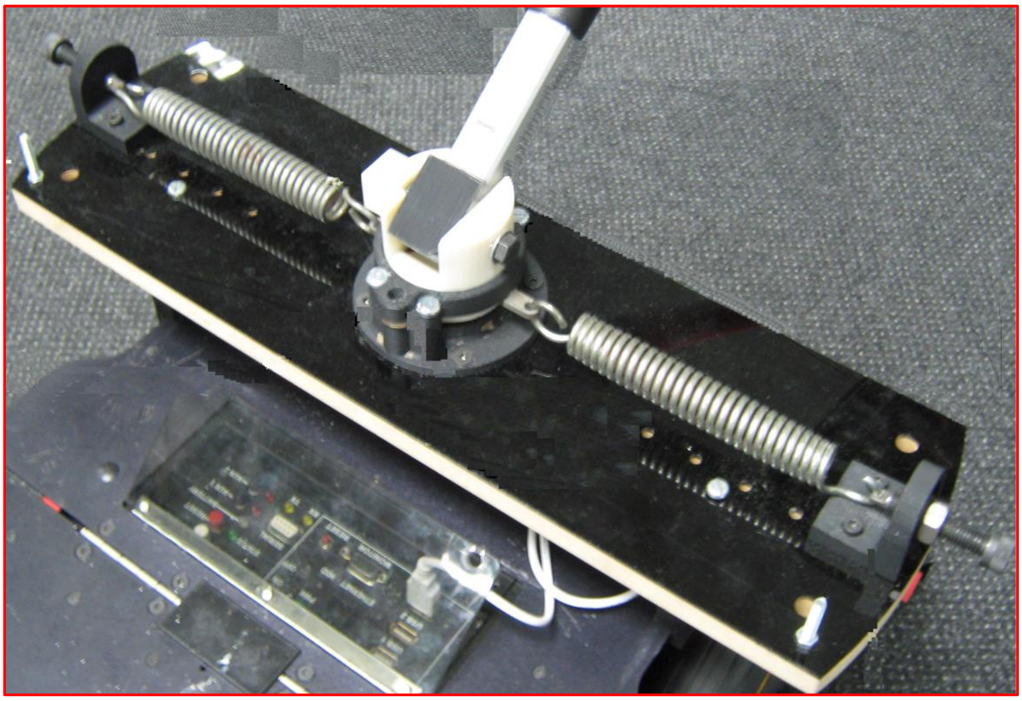


Figure (2.9) Spring system (adapted from, Ghosh et al., 2014)

In some experiments, the robot followed a pre-programmed route and the blindfolded follower followed the robot. In these experiments, a problem appeared when the *robot turned left or right quickly*, in such cases the robot must give pre-emptive notices to the follower. The intelligent rein can give these pre-emptive notices when the robot turns left or right by sending a haptic indication to the follower. From the previous review, it can be concluded that an intelligent system with feedback of the environment and perceptual capabilities can enable and enhance navigation in complex environments this intelligent system depends on use of some electronic and mechanical components have high accuracy and efficiency. Additionally, the use of haptic communication can be considered as a suitable approach of providing information to the follower as the least affected approach of communication.

Chapter three

PROPOSED DESIGNS

3.1-Introduction

There have been several attempts made to guide auditory and visually impaired individuals, also for people who work in environments where visual sense cannot be used. For example, fire-fighting personnel who are dependent on the touch sensation (haptic) of side walls for localizing and physical ropes to essentially provide direction/navigation (Ranasinghe et al.,2015). Bases on the previous chapter, it is clear that the previous design of the rein can be used and further developed/enhanced to emulate the interaction between the visually impaired follower and a guide dog. To complement the previous efforts, it was necessary to investigate and propose new methods in an attempt to achieve the natural and intuitive shared control relationship observed between a dog and human. In this chapter ,the interface strategies will be classified into two distinct modes: coded haptic messages which can covey messages in stream of codes and direct force haptic feedback/control which can convey messages in the shape of direct movements. Also, the preliminary test will be done to confirm the previous studies by making the rein fixed and observing the follower/robot path, especially during rotation. Moreover, methods and a plan of study is proposed in order to analyze the potential options and consequently select the most suitable and more capable method to apply and experiment with in the university lab. Each method will be studied with respect to general idea, design and ability to apply in the university. A range of methods have been proposed, including those based on actuation by electromagnetism which includes electrically and mechanical parts. Table (3.6) provides a comparison between all the reviewed methods is also presented.

In order to achieve this, an analysis was made of movement types (i.e. rotation, elevation) to know which of them can be exploited to achieve optimum follower interaction with the haptic rein. The chapter will explain in detail the preliminary tests, all the proposed methods and compare them to choose the best and most appropriate one.

3.2-Preliminary system test

Based on the previous research it was decided that a preliminary test would be undertaken to establish baseline parameters and the system requirements. This test aimed to determine the follower behaviors in terms of comfortability and his ability to closely follow the robot path, and to establish the limitations in the current setup/design and help understand the follower requirements for the next design phase.

In order to determine and characterize the performance of the designed systems, the test parameters were split into 2 fundamental areas based on the system's ability in relation to:

A) Minimizing the deviation between the robot path and the path of the follower

B) Maximizing/optimising the comfort and intuitive interaction of the follower during the complete journey.

These factors are analyzed and evaluated in the following way:

For A) a video-based analysis showing the path of the follower steps is analyzed (review all steps taken by the follower when following the robot and making a cumulative images for all these steps then connect them with each other to make virtual path) as seen in figure (3.9), thus illustrating how much deviation is evident between the follower and robot path.

For B) the perceived comfort was evaluated using two methods: A follower questionnaire and the continuous measurement of force being exerted on the follower during the experiment.

The measured force provides an indication of the follower comfort which is inferred from the resistance/compliance applied by the rein to the follower's arm.

Preliminary system test is performed in the university area using a mobile robot, wireless connection and sensors to know the value of tensile force that occur between follower hands and rein, and to find out what happens when follower follow robot and the rein is fixed. For this, a 769.8 cm path was drawn with rotation to left and right, this path will be followed by the robot and the follower will inevitably follow the robot

By tracking and drawing the cumulative follower steps, the path known and the amount of follower/robot path deviation in both directions (when robot turn left/right) is calculated. This deviation can be reduced by installing a haptic system (because smoke, dust and noise around the follower) that makes the robot and follower collaborate to walk on the same path, in the first step the system was installed and the rein was made fixed then the path which the robot should follow is drawn on the ground. Figure (3.1) shows the path which the robot will follow.

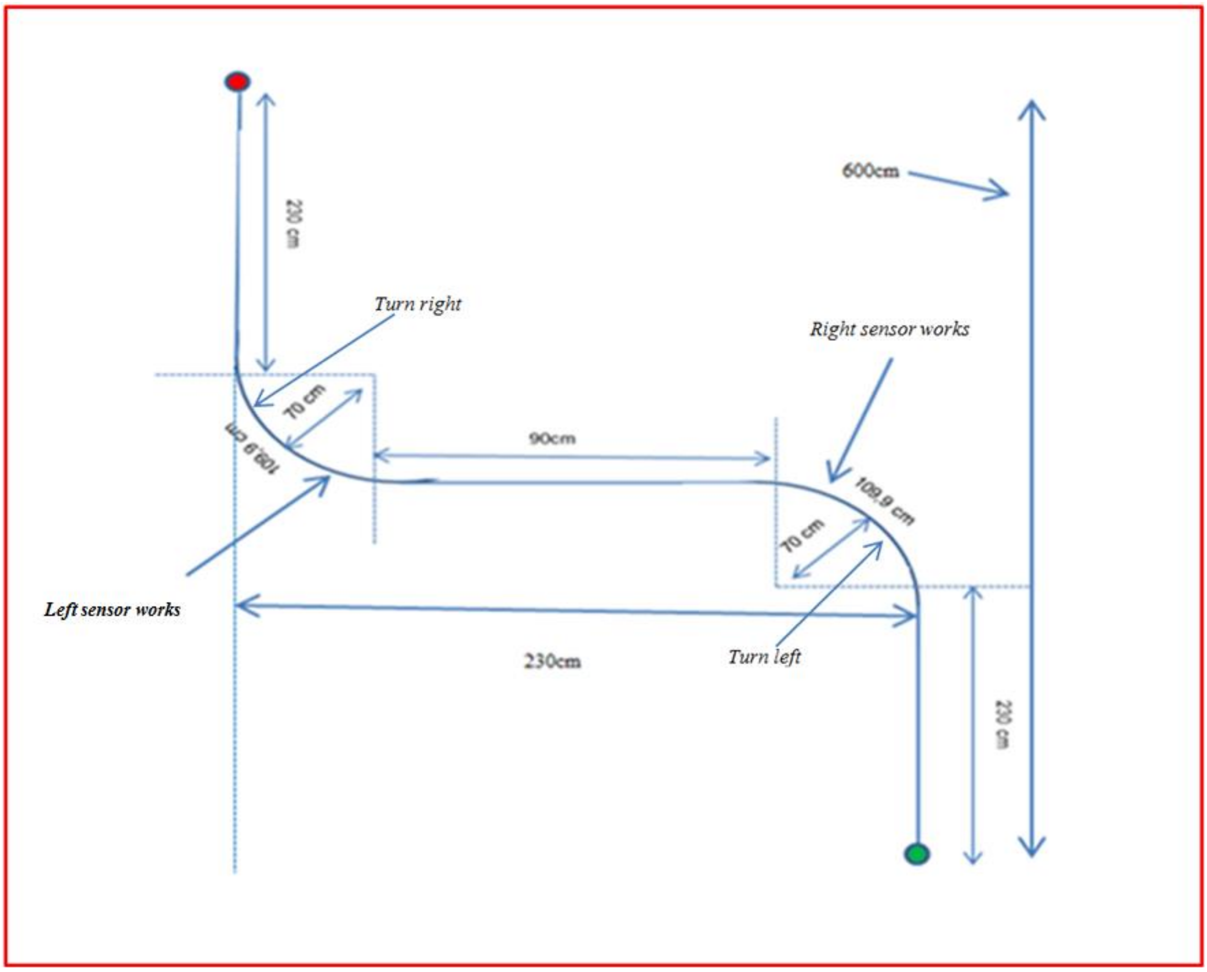


Figure (3.1) Test path

Through the figure, the total distance to be traversed by the robot is 769.8 cm. Using the predefined robot speed of 17.70 cm/s, the time needed to complete the route is 43.47 seconds. A group of university students were invited to participate, and with each participant, the experiment was explained in terms of method and purpose. The experimental procedure sheet, follower questionnaire and consent forms are given in appendix (A). The explanations given to the follower included a basic overview of how the participant follows the robot, the number of tracking trials, and the test questionnaire form, which asks for the level of comfort in a range 1 to 5 in forwarding, turn left and turn right direction as subjected data. The participant (he/she) cannot see or take an attempt before the actual test begins, and that's for the neutrality of the results. Figure (3.2) shows the fixed rein.

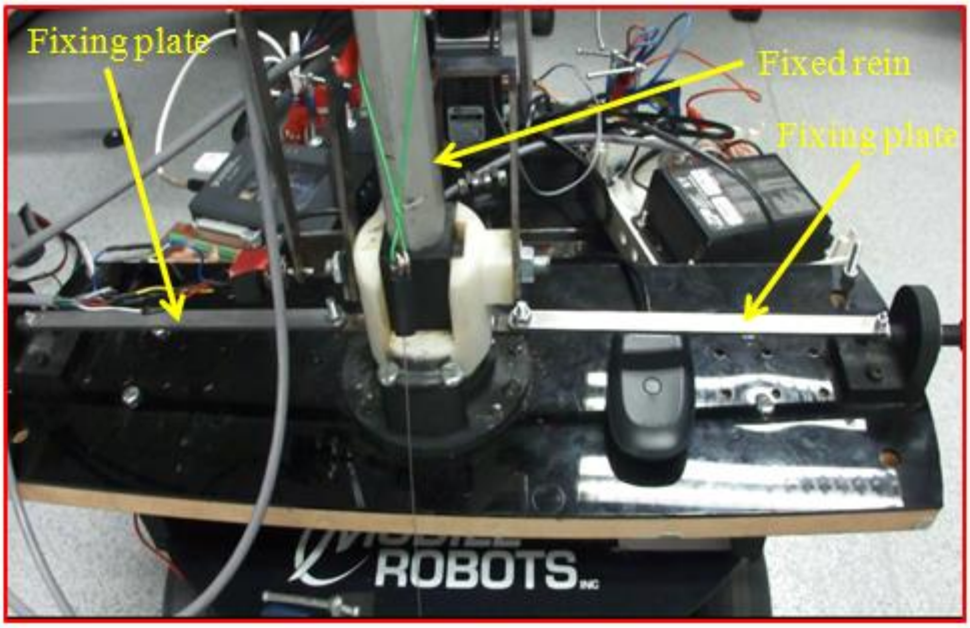


Figure (3.2) Fixed rein

3.2.1 Preliminary test methodology

The test protocol is (a) invite 5 participants from university students these participants have age over 18, their arms haven't injuries and gender does not matter and with average height, the whole test procedure is explained to all participants. (b) Participants right arm was attached with the wrist strap which connected to the rein. (c) The Participants put on a blindfold as shown in figure (3.3). Subsequently, the robot movement was started with no external prompt and moved forward to 230 cm, then rotate to left on a circular route by a distance of 109.9 cm and continued to move forward by a distance of 90 cm. This is followed by a rotation to the right using circular rotation with a distance of 109.9 cm. The final section of the path continued forward 230 centimetres and stopped, completing the entire journey.

Figure (3.3) Participant following the robot

(d) When the set path has been traversed the robot stops. The participant also stops and removes the blindfold while the researcher presented the survey form to be filled by the participants. The data for each participant is gathered and put into the table to be analyzed. In forward movements all participants choose comfortable level 5 which was100% of samples. When the robot turned left there are 2 samples (40%) choose level 2 of comfortability level and 1 sample (20%) choose level 3, the other 2 samples (40%) choose level 4. However, when the robot turned right 3 samples (60%) choose level 3 of comfortability level and 1 sample (20%) choose level 4 where the last sample (20%) choose level 5. Table (3.1) shows the collected data and explains the number of samples chose the level on the total number of samples (participants).

Comfort level	1	2	3	4	5
Forward	0	0	0	0	5/5
Turn left	0	2/5	1/5	2/5	0
Turn right	0	0	3/5	1/5	1/5

Table (3.1) Test subjected data in forward, turn left and turn right (person / (5 = total participants)

3.2.2-Preliminary test data analysis

From preliminary analysis of the table (3.1), it's clear that the participants are very comfortable when the robot is moving forward, with most of the participant's haveing chosen the fifth level on the comfortability index. Less comfort was observed when the robot rotated to the right with most of the samples (participants) distributed after the middle of the index comfortability 2.5. And in the turn left which the least rank there are 2.5 people less than index level. An increased level of comfort was observed in turn right as compared to turn left, and this is maybe the result of sudden left rotation or may because of all the participants held the rein with the right hand. Following figures (3.4), (3.5), (3.6) showing that.

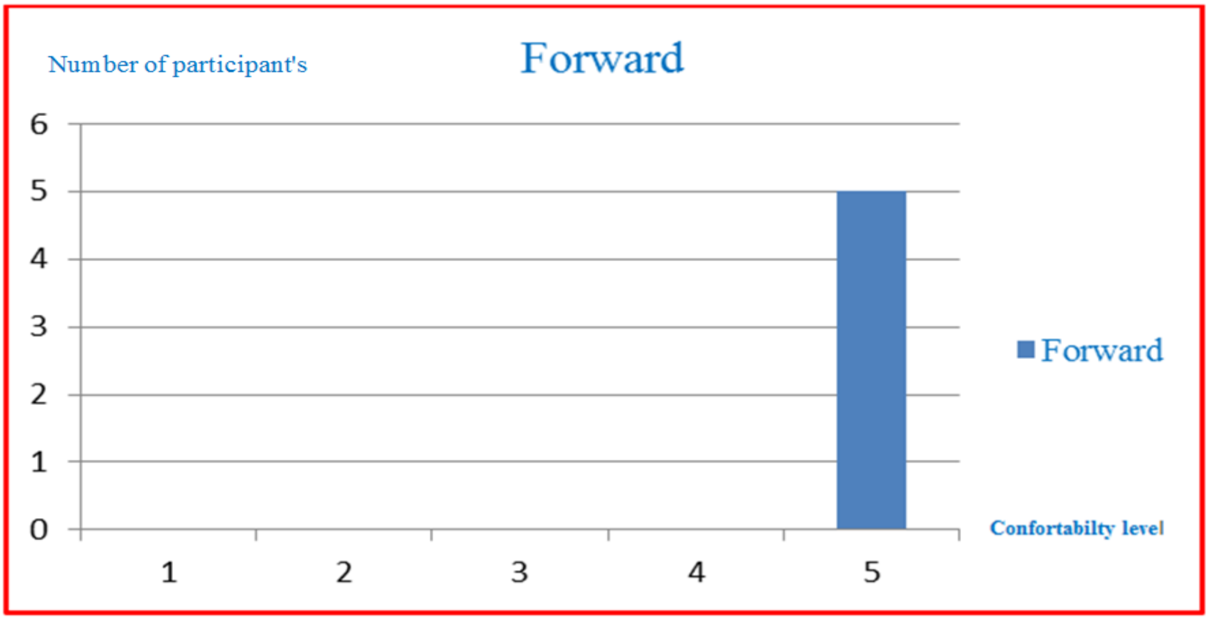


Figure (3.4) Participant /comfortability level (Forward)

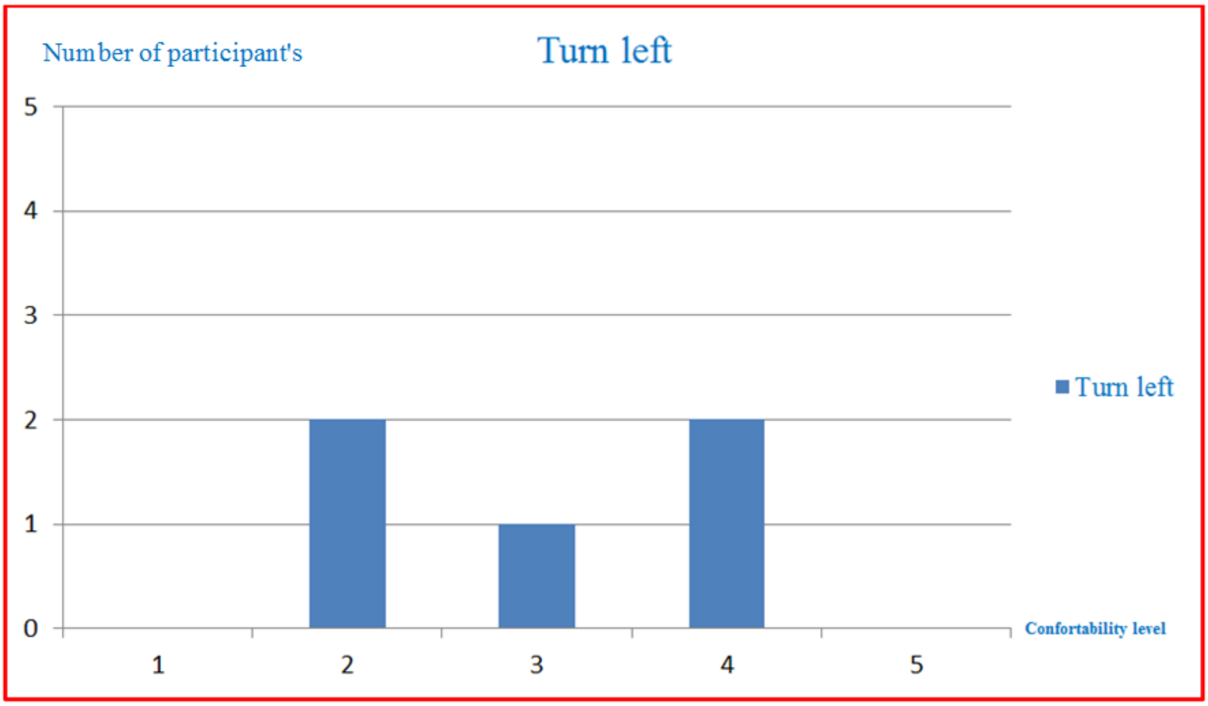


Figure (3. 5) Participant /comfortability level (Turn left)

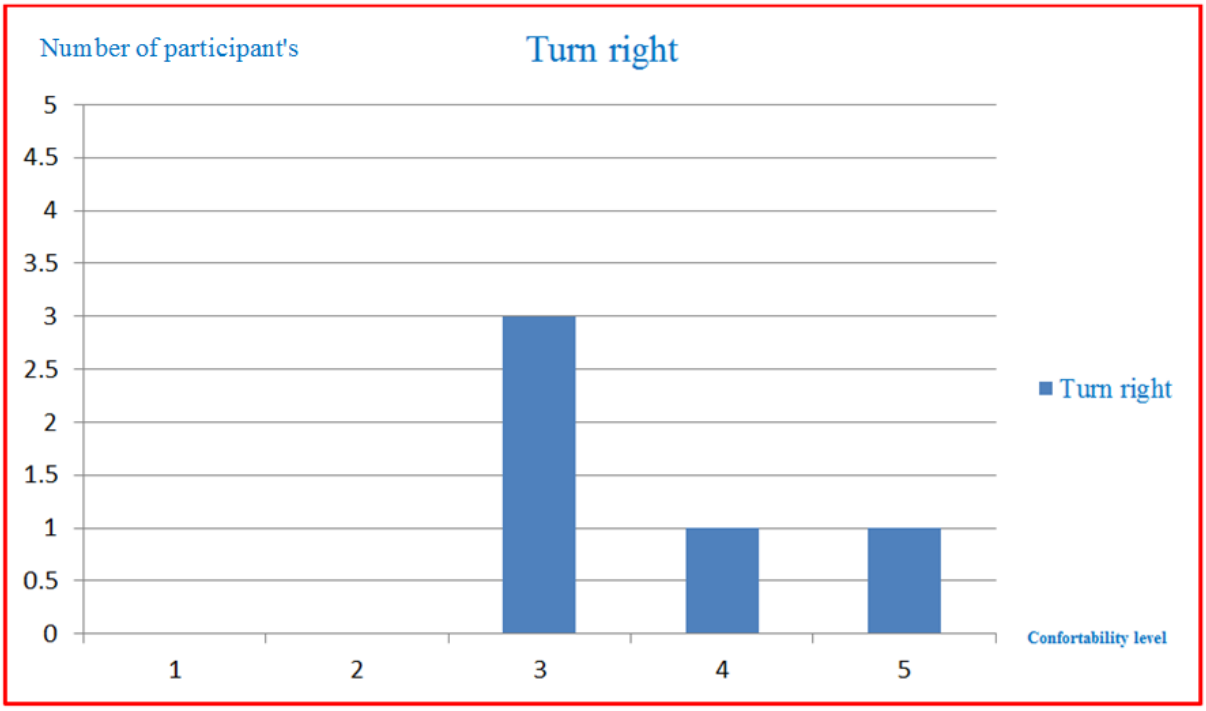


Figure (3.6) Participant /comfortability level (Turn right)

3.2.2.1-Objective data collection

The objective data obtained from the sensor (load cells) readings which indicates the tensile force that occurs between the follower right arm and the rein (between the grip which is hold by follower and the rein axis) were collected, analyzed and plotted,and the following. Table (3.2) demonstrate highest and lowest rate for the left and right sensors and in which readings were occured, the word reading in next table means the data will take from the sensor.

Sample (Participant order)	1		2		3		4		5	
Right / Left (Sensor)	LS	RS	LS	RS	LS	RS	LS	RS	LS	RS
Highest rate	8	7	5	7	5	5	6	8	5	8
Data reading order	31	30	55	32	82	67	55	33	78	26
Lowest rate	0	0	0	0	0	0	0	0	0	0
Data reading order	32	31	34	86	86	68	57	36	80	29

Table (3.2) Objective data demonstration

To understand the previous table the following is the description of the third sample. In the third sample (Participant), the highest rate achieved by the right-sensor is 5Nm at reading 67 and the lowest rate is 0Nm at reading 68, and the left-sensor has achieved the highest rate of 5Nm at reading 82 and the lowest rate is 0Nm at reading 86. Figure (3.7) shows dataset of the third sample (Participant) during one cycle of the path as an example where LS(left sensor),RS (right sensor), and Appendix (B) shows all samples data.

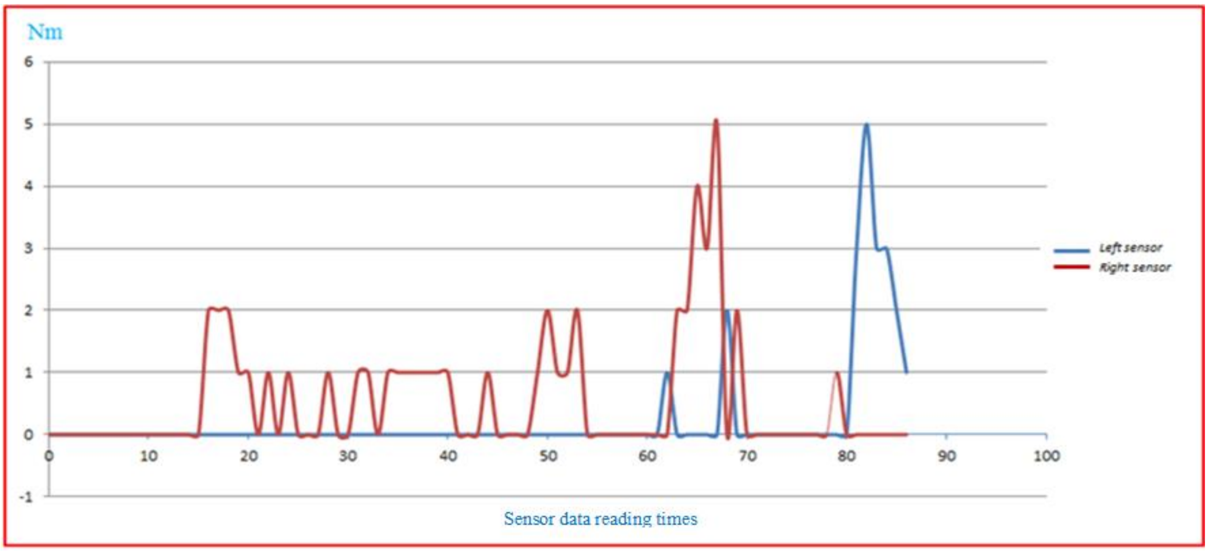


Figure (3.7) Shows an example dataset during one cycle of the path.

To be clear the figure (3.8) shows the highest and lowest reading of LS/RS sensors in all samples.

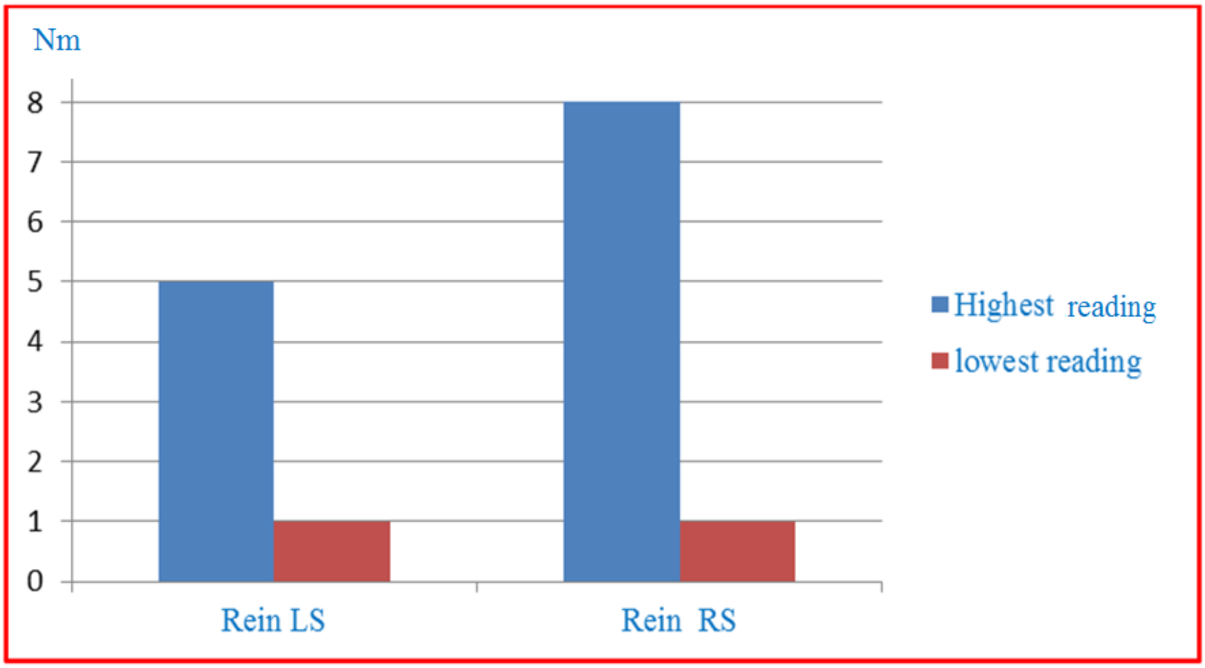


Figure (3. 8) Highest/lowest rein LS/RS sensors reading

Table (3.3), shows the maximum reading of tensile force recorded through the whole path, noted that the maximum tensile force has been receded in the turn right side 8 Nm and turn left is 6 Nm.

Sample (Participant order)	1	2	3	4	5
Maximum reading in forward	3	0	2	0	2
Maximum reading in turn right	7	7	5	8	8
Maximum reading in turn left	5	5	5	6	5

Table (3. 3) Maximum readings forward, turn left and turn right of the robot

3.2.3-Preliminary test follower path analysis

After the test was finished, a typical follower path was reviewed and tracked by plotting a cumulative steps location of follower to creating a virtual path and comparing with the actual robot platform path. The deviation between the follower and robot paths can be determined and used as a reference to know follower can follow the robot in the same path smoothly or has difficulties

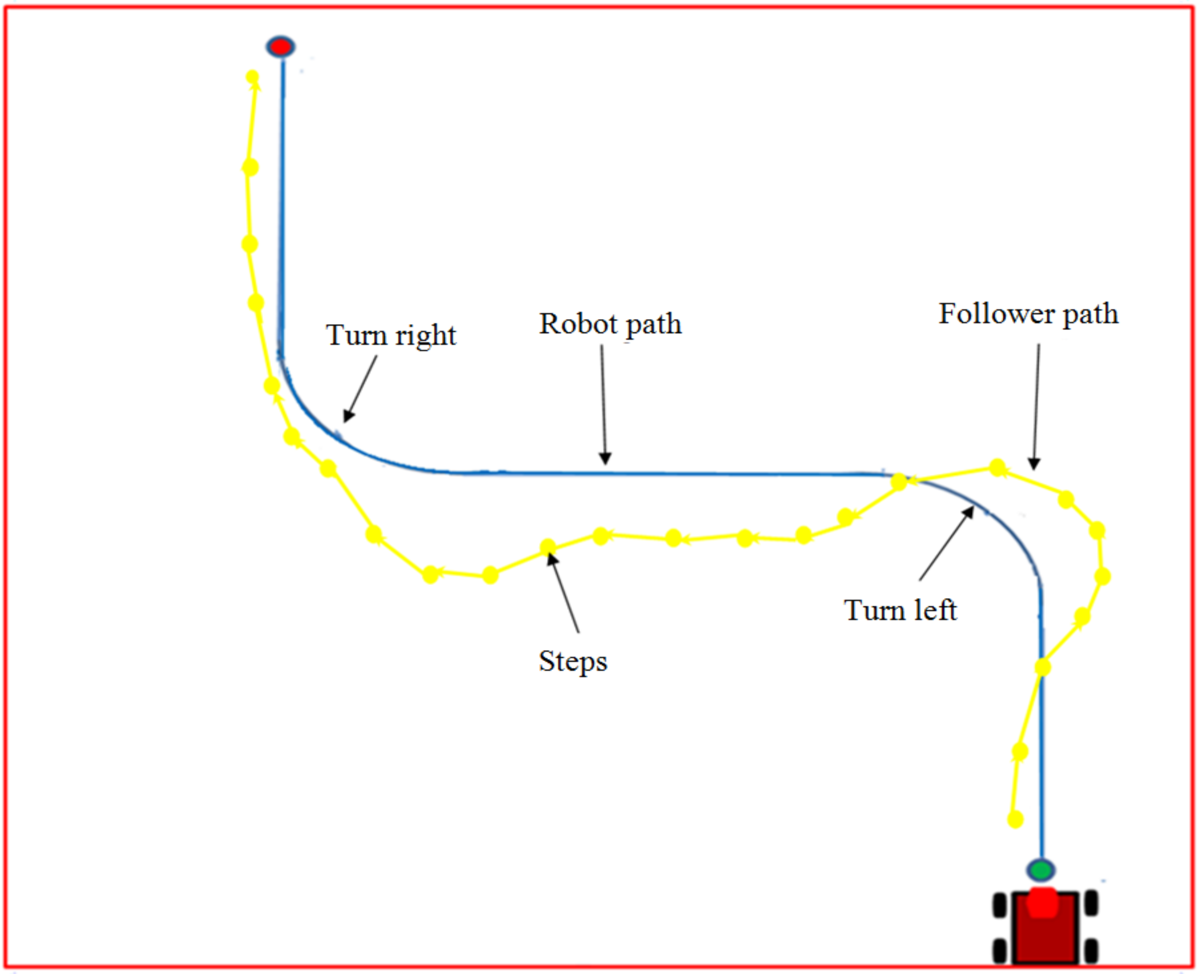


Figure (3.9) shows follower /robot paths

It is clear the deviation in the turn to the left is higher than in the right and may be caused by many reasons such follower hand position as shown in figure (3.9) where the follower path has yellow color and robot path blue color.

3.2.4-Preliminary test Conclusion

1- After the data is collected and analyzed the subjects data show that the straight path is the most comfortable for the participants and the turn right is second in comfortability feeling, the turn left is the least comfortable action, and this may be due to the ability of the participants to be familiar with the robot movements or through the use of follower right hand.

2- The participants do some staggering during the following of robot and it is clear from some registered readings this happen before and after the completion of the rotation as shown in figure (3.7), and this is because the follower feels a lack of confidence as a result of the eyes tied, and they cannot see the path.

3- Through the analysis of objective data, there are readings of the sensors in both directions which indicate the participant's stagger or are jolted by the movement. This was seen visually during the experiments and is evident in the measured force data between the follower and the rein. The resistance/force between the follower's arm and the rein is bigger when the robot rotates to the left and reaching up to 8 Nm as when compared to a turn to the right which achieved a maximum limit to 5 Nm, as shown in the figure (3.8)

4- Through the previous analysis, it is clear that to optimize the level of comfort the tension/resistance (by minimize the tensile force) between the follower and the rein must be considered. Limiting excessive values of force being applied to the follower through a more progressive and controlled application of force throughout the turn are desired.

The rein should therefore move/adjust in harmony with the robot movement to decrease the tensile force in the rein and help the follower to track the robot. For example if the tensile strength increases over 2Nm, this is an indication which means there is rotation and the robot should *reduce the speed* of the turn and at the same moment the rein should *move* in a direction to reduce the force on the follower caused by the robot’s rotation; helping the follower to comfortably follow the desired path.

5- Through the analysis of the follower steps path the rein clearly shows a significant deviation between the robot path and follower path, this was at its greatest when the robot rotates to the left.

6- Efforts should be made to reduce the deviation by using a system of intelligent understanding between the follower and the rein; this system can be based on the force haptic feedback.

3.3-Dimensions of design space

In this research, haptic messages will be sending from the robot to the follower. There are many ways in which these haptic messages can be transmitted. These include vibration, electric pulses, air wave's direct printing in follower body and other haptic methods.

In this project several criteria have been developed for the design and selection of haptic messages transmission and coding methods, the most important criteria are:

- Clarity of messages intensity, that can be easily understood by the follower without confusion
- Easy and intuitive to learn and be repeated
- Can be used to send a haptic control signal from follower to robot also can send feedback from robot to follower, that means it can be considered as bidirectional data bus media
- There is a suitable size vocabulary available to encrypt messages
- No impact on the health of follower.
- Can be easily interface/attached with follower body. Especially the hand and fingers because they are suitable for the movement as indicated by several researches (Srinivasan, 1995).
- The possibility of installation and testing within the university laboratory
- Availability of materials for the implementation. For example, some method may need additional digital equipment does not found in standard suppliers.
- Availability of references and accessibility, to build any of these methods need some references and these references can be research paper or books or access websites

- The possibility of experiment within the university area this means there is no special requirements for experience the method and does not need to get help out of university for example does not need to practical out tests, public test samples. This makes the issues less and helps to achieve the design within the project time.
- The existence of high completion rate with research time allowance. Because the research has limited time for that the expected compilation time must be within the limited time constraints
- High proven effectiveness of the method, this means the method must achieve it targets
- The cost of the material is reasonable not to exceed the budget as any research the fund and budget has the big role of research finishing so estimated material does not exceed the budget
- The presence of the software's necessary to run and implement the method, and make sure it can get in the university software library
- There are no predicted technological obstacles that may face in the future

In general, haptic feedback depends on the used part of the human body; the following section identifies some dimensions that must be considered in the design space:

3.3.1-Feedback technologies

There are several distinctive innovations available that initiate haptic feedback. One of the foremost common technologies is vibration feedback that's used in most mobile phones; tablets or game controller. Other feedback advances incorporate (Electric Muscle Stimulation) (EMS) feedback or air currents. Such innovations have various capacities to provide feedback ranging from tactile prickles on the surface of the skin or physical haptic of limbs movements, (Okamura et al., 1998).

3.3.2-Sensing capabilities

Haptic sensing capabilities are based on the distinctive nerves within the skin, tissue, and muscles all of which are invigorated by touch, pressure, and heat. Besides, the number of nerves changes at a distinctive place on the human body (Silvera et al., 2015). Hence, a few places are more delicate to haptic feedback than others. For example, the fingertips are exceptionally delectate compared to the back. This need of affectability can be adjusted by the estimate of fortified range, (Pfeiffer et al., 2014).

3.3.3-Position on the human body

In the case where haptic feedback is connected through a gadget on the follower's body, a number of distinctive positions are conceivable. These include the finger, lower arm, the upper arm, the middle, the head, the legs, and the feet (Hoggan,2013) .Applying feedback to each of these positions works well, and the choice for a position ordinarily depends on the activity for which feedback ought to be connected (playing football vs snatching something with hands) (Pfeiffer et al., 2014).

3.3.4-Stimuli characteristics

When applying the feedback, the following characteristics have an impact on haptic recognition: the quality of connecting stimuli, the strength of the applied stimuli, the length, and the stimuli shape over time (Pfeiffer et al., 2015). The form of the haptic stimuli can follow the characteristics of a continuous, a substituting (on/off), or an increment or diminish sequence. Combinations of this stimulus make diverse beat over time, (Tamaki et al., 2011).

3.3.5-Feedback Type

Haptic feedback can be used for many purposes. Max Pfeiffer defines haptic feedback as being used to make a follower aware of a particular situation. Also, he defines informational feedback as transmission of information (e.g., Morse code). In addition, this can be used to transfer information in a manner that protects privacy. Haptic feedback can be electric (EMS), vibration or movements to guide the user.

3.4-Proposed designs

In this section, there are many ideas proposed for design and implementation, all aimed at providing information and control of the two fundamental parameters required: the follower direction and speed.

The interface strategies can be separated into two distinct modes: 1 coded haptic message which can covey messages in stream of codes such as stings or pressure acting on follower skin; 2 direct force haptic feedback/control which can convey messages in the shape of direct movements acting on follower body. The following section explains the details of proposed designs and has been split into two parts first describe interpreter cuffs as message based and the second describes the full movement as direct control/intervention /force feedback based. Each strategy has its own advantages/disadvantages and will consequently be evaluated against the requirement for the project. Figure (3.10) shows the block diagram of interface strategies

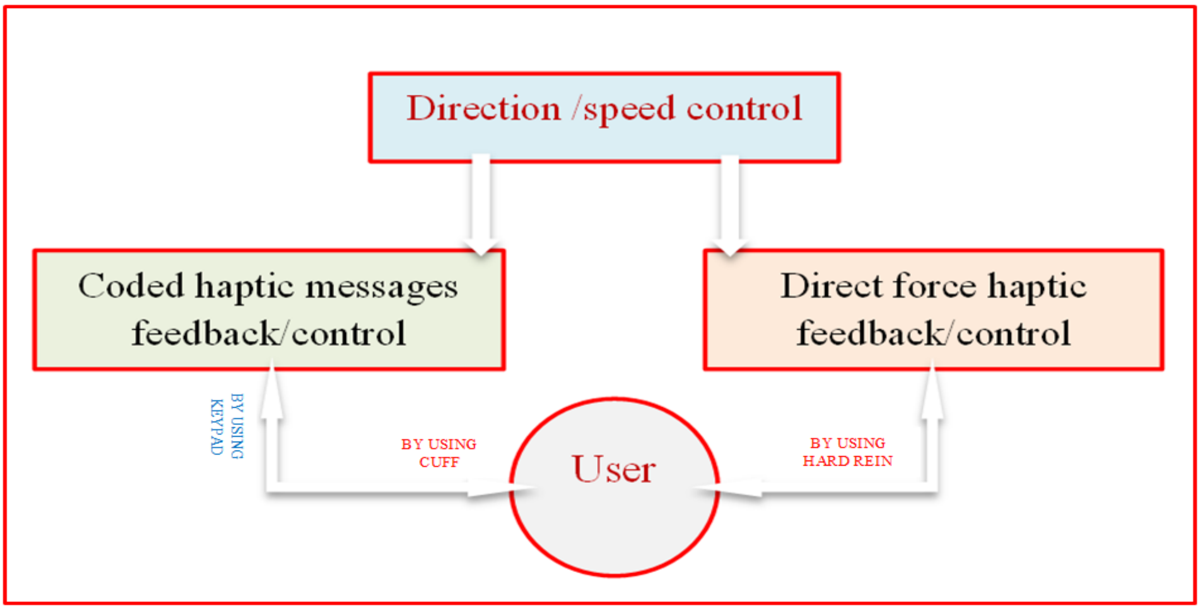


Figure (3.10) The interface strategies

Coded haptic messages may be conveyed to the follower using several different techniques and technologies. Several researchers have successfully utilized a follower interface cuff which can receive codes and change them to haptic signs to achieve human-robot interaction. The ideas are designed around the constraints that one person with limited auditory and visual perception of the environment (a follower) is guided by robot with some capabilities (a guider). The ideas of design should be consistent with the mentioned criterions.

The coded cuff-based design could be adapted to provide control through for example keypad/joystick control. However, the additional complexity, response times of the follower to input the message and requirement of knowledge of the codes makes the approach cumbersome and lack the intuitive nature desired.

The rein in this thesis is defined as a tool that connects the follower with the information transmitted via the rein connected to the mobile robot with number of messages have limited vocabulary range (such as turn left/ turn right, forward /backward speedup/ speed down) table (3.2) shown some of interpreted vocabulary.

3.4.1-Haptic interpreter cuffs

1- Electromagnetic haptic interpreter cuff.

2- Electric pulse haptic interpreter cuff.

3- Haptic printer interpreter cuff.

Each of these methods is to convert the incoming signal to the follower. On this basis, these methods are the conductors of the haptic feedback.

3.4.1.1-Description of the proposed electromagnetic haptic interpreter cuff

In this section, an electromagnetic field is proposed as a method to interpret haptic feedback from a robot or controller to give some meaningful haptic feeling to the follower in the form of pressure point this feeling to reflect some meanings can follower understand and change them to actions. Figure (3.11) shows the general structure of the proposed method, as shown in the figure the current flow from electric code generator device to control unit which changes the requests of the robot/controller to electric current flow with different time periods. This electric current is applied to the coils which cause changes to magnetic forces distributed over the cuff and cause attraction and distraction of iron rings. The variation in patterns and their time dependence can be used to describe some commands or language that the follower can understand.

Iron rings stay in the middle of the cuff up to the desired coil changed to magnetic in that case the ring attracted to the coil and make pressure on the follower arm, this pressure conveys some information to follower, in general follower can receive a number of pressure points in his arm and this pressure points have the same strengths but spread all over the follower arm (which is covered by cuff) and compounded with each other to do stream of codes which the follower can interpret and understand them and based on, starts the appropriate actions requested by robot.

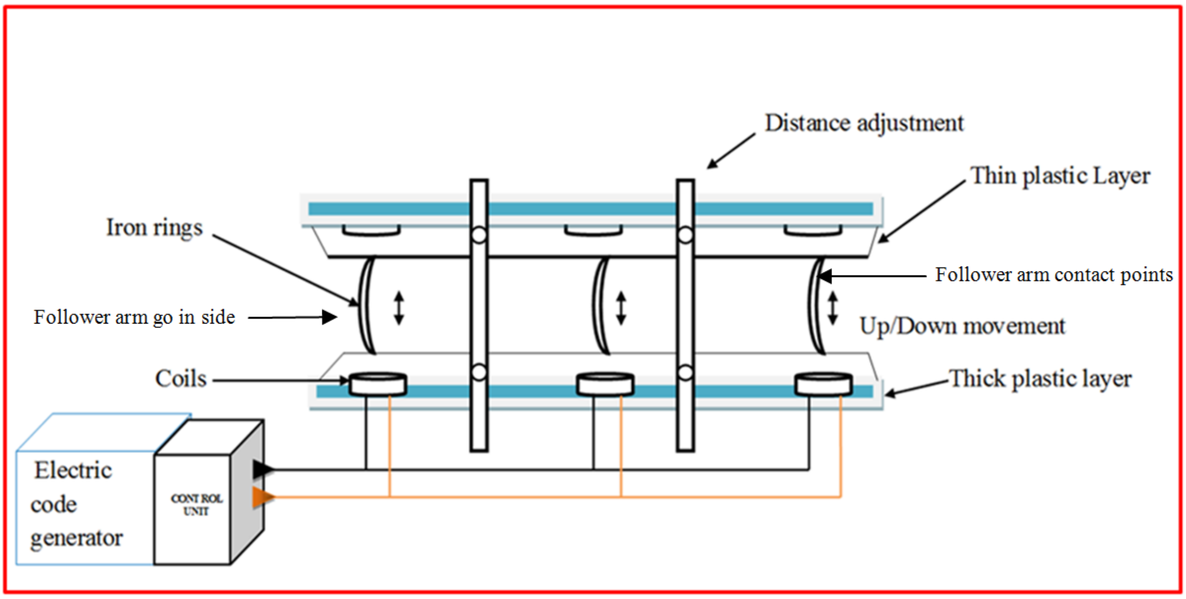


Figure (3.11) Electromagnetic haptic interpreter cuff

3.4.1.2-Description of the proposed electric pulse haptic interpreter cuff

This section will discuss the use of electric pulses to interpret the haptic feedback from the robot and give some haptic feeling to the follower, these electric pulses convey some messages follower how can interpret them and converted to actions (Krueger et al.,2014).

The figure (3.12) shows the general structure of the proposed electric pulse interpreter cuff'. As shown in the figure the pulse flow from the pulse generator unit to the control unit which interprets the requests come from the robot/controller and converts them to electric pluses flow with different time periods. The electric pulses are distributed on the pulse heads and describe predefined messages which follower can understand.

These pulses formatted in codes of (on, off) and make stings on the follower arm. These stings convey some information to the follower. So in general, the follower can receive a number of stings his arm and these stings have the same intensity but are spread in time and locality. The stings can be compounded with each other to form a stream of codes which the follower can interpret and understand; consequently, changing them to actions as requested by the robot/controller system. The stings could be enabled to have different strengths/intensities in order to facilitate a larger number of codes for carrying messages.

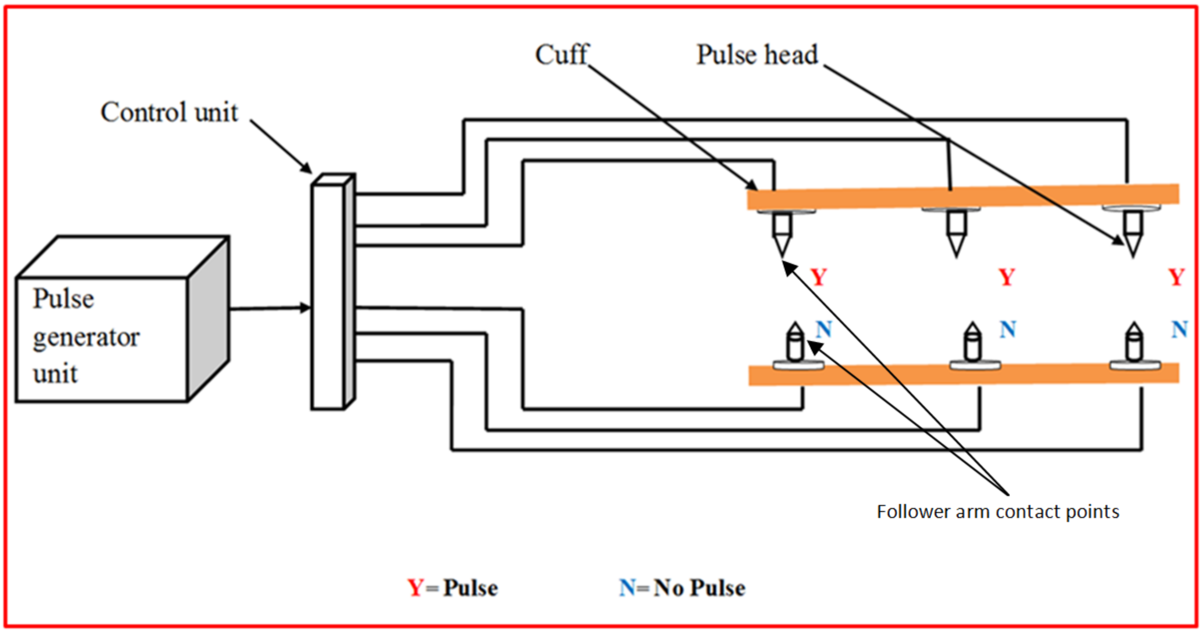


Figure (3.12) Electric pulse haptic interpreter cuff (multiple heads)

In the proposed electric pulse haptic interpreter cuff the pulses may be taken parallel shape as in the figure (3.12), that means the cuff has a number of pulse heads and the codes come to the follower arm in a parallel manner this number of digital codes is dependent on the number of cuff heads. Alternatively, the code may come to the follower arm in serial format where the cuff has only one head and presents the code bit by bit using pulse duration and intensity to convey the information as shown in the figure (3.13).

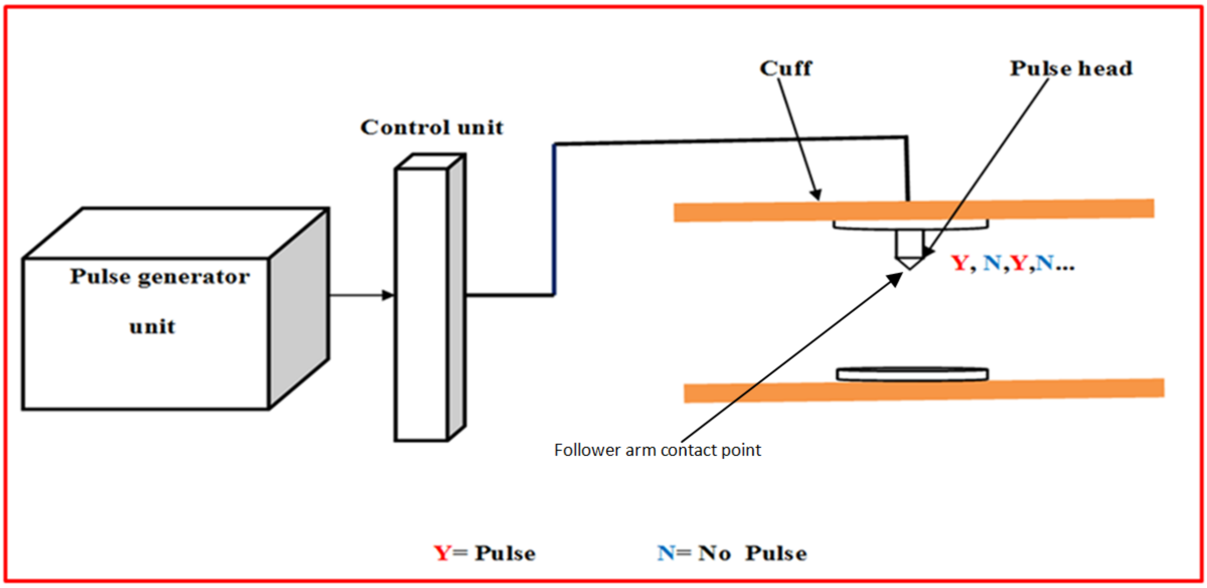


Figure (3.13) Electric pulse haptic interpreter cuff (one head)

3.4.1.3-Description of proposed haptic printer interpreter cuff

In haptic printer interpreter cuff method, a similar concept to touch screen for blind people is used however the basic arrangement is reversed. For example, in a touch screen system the follower can touch different parts of the screen to distinguish his aim (Buzzi et al., 2013), in haptic printer interpreter cuff the letters will print on the skin of follower arm, these examples will be described to explain the idea. This section will try to use haptic printer interpreter cuff to interpret the haptic feedback from the robot and give some haptic feeling to the follower by writing large alpha letters on the follower's arm. These letters give feeling to the follower and reflect some messages; the follower can convert them to actions. The figure (3.14) shows the general structure of the proposed interpreter haptic printer cuff, as shown in the figure the signals flow from interpretation unit to control unit which gives commands to the printer head which sends commands to the specific pins according to the letter shape. These pins extend out from the printer head and apply pressure points on the adhesive tape placed on follower skin exact as the letter shape which interprets the requests come from the robot/controller. The letters are distributed on the follower arm by movement of the head and describe some messages which follower can understand. Notes: these letters are printed letter by letter to make distinguishable codes.

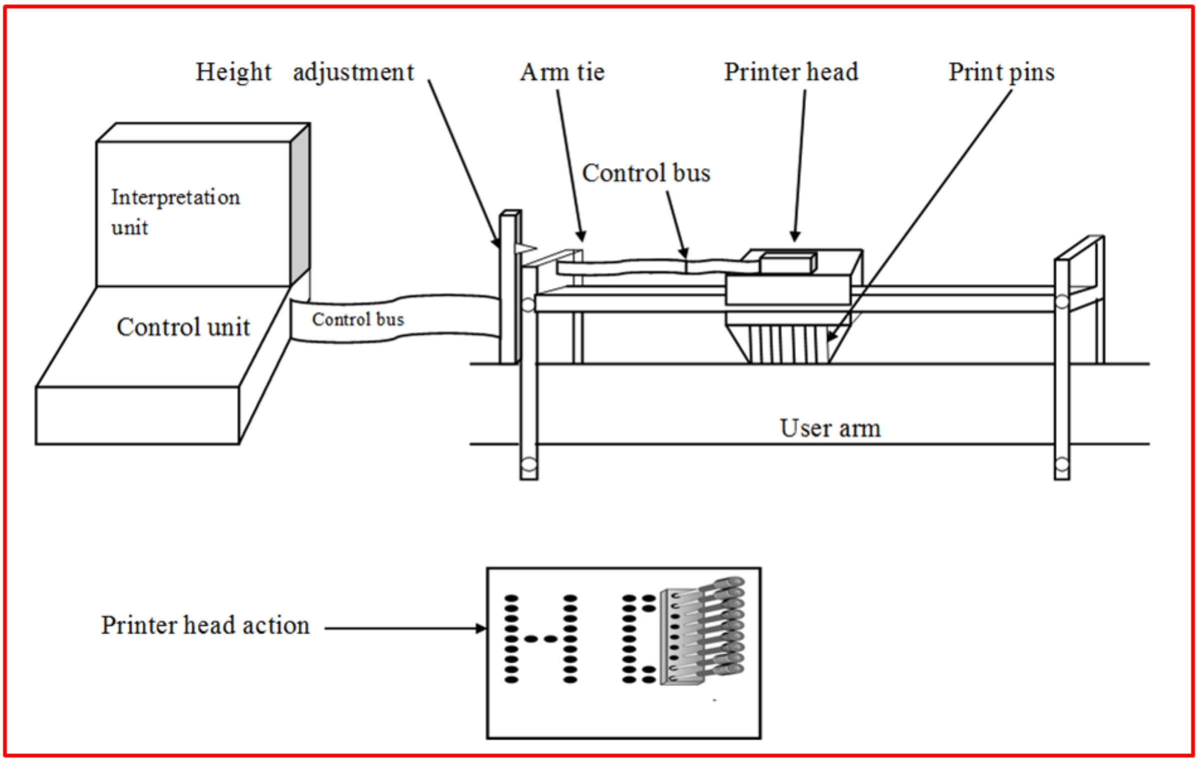


Figure (3.14) Haptic printer interpreter

3.4.2-Description of full movement rein proposal

In this section, the movement rein will be explained as a proposal to convey the feedback from the robot to the follower, as well as the control from the follower to the robot. A range of rein development possibilities was investigated to maximize the code spectrum and for potential future development purposes. Two examples include rein attached via telescopic junction and rein attached via rotating grip-based handle.

3.4.2.1-Basic movements of one-part hard rein with fixed grip and rein with (ball /side) joint

In this research, a hard rein is proposed as the main part and to get maximum movements, telescopic junction and movable grip are connected to hard rein and considered as additional parts. An analysis of all possible movement was made to in order to establish an optimal design/solution. In this research the movement of hard rein is called basic movement and it moves in (forward/ backward dirction only) if the rein attached with the side joint as shown in figure (3.15,a), and (3.15 b) a ball joint is used the movements will considered in four direction (right/left and forward/backward directions). Moreover, if the hard rein has section 2 added (telescopic junction and movable grip) in that case the movements of these parts consider as compound movement and are described in detail in the following sections.

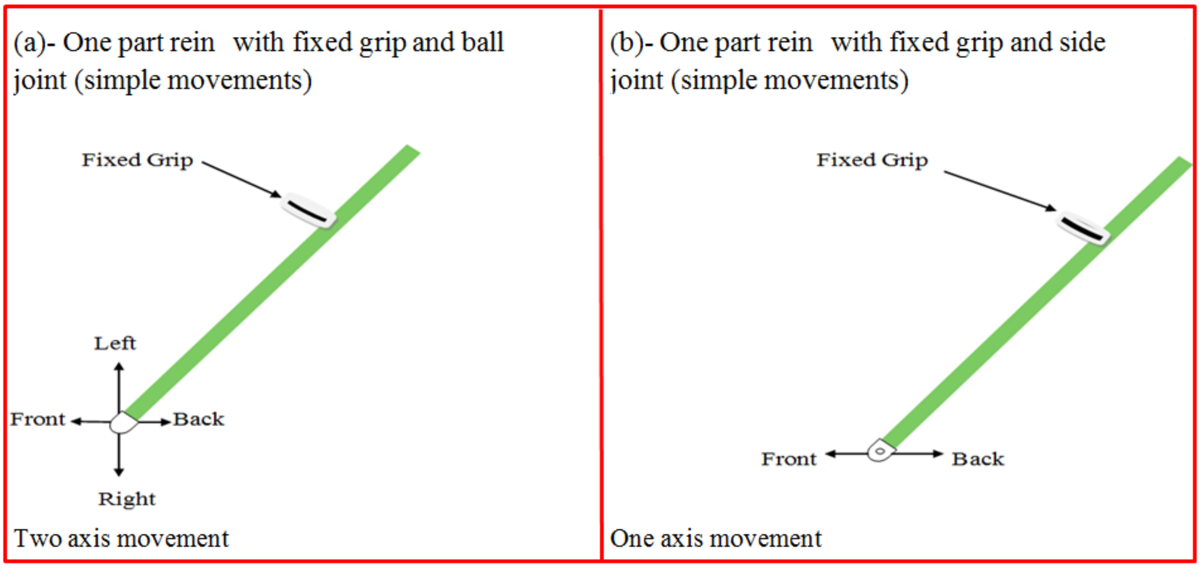


Figure (3.15) Simple movements of, (a) one-part rein with ball joint, (b) one-part rein with side join

- ***Movement analysis:***

This section explains the possibilities of hard rein movements. As shown in figure (3.15a), the simple movements of one-part hard rein with fixed grip and ball joint are taken into two axes (right/left, front/back) and in figure (3.15b), simple movements of one part rein with fixed grip and side joint are taken into one axis only (front/back).

3.4.2.2-Compound movement of two parts rein with ball joint/moved grip

To increase the possibility of rein movement an additional structure such as a telescopic junction and movable grip is required. Two parts rein (rein and Telescopic junction can be twisted) with ball joint is shown in figure (3.16 a) and the two parts rein (rein and Telescopic junction) with ball joint and movable grip is shown in figure (3.16 b).

-*Movement analysis*:

This section explains all possibilities of rein movements. As shown in figure (3.16a) the two parts rein (rein and telescopic junction) with ball joint movements taken into three axes (right/left ,front/back) and (up/ down) and (twist left and twist right), and in figure(3 .16b) the two parts rein (rein and Telescopic junction) With moveable grip and ball joint movements taken into three axes movement of rein (right/left, front/back) , movement of grip (twist left and twist right) also movement of grip (left/right, up/down).

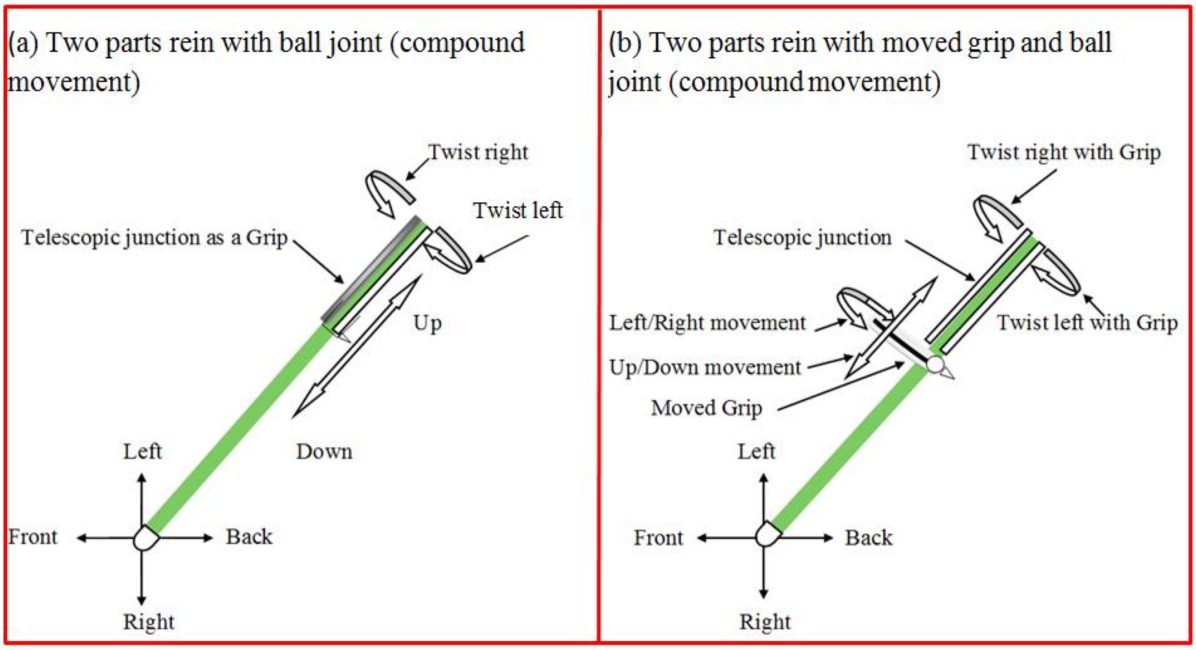


Figure (3.16a, b) Compound movement of two-part rein with ball joint/moved grip

3.4.2.3-One/two parts rein with ball joint and movable grip with (mode button)

For simplicity, it is possible to remove additional structures such as the telescopic junction and let moved grip in one part rein with ball joint and moved grip as shown in figure (3.17a), if the simplicity does not has first priority but functionality in that case can add control button to increase functionality of the rein as in figure (3.17b), which shows the two section rein (rein and Telescopic junction) with moved grip, ball joint and control button use to on/off control /feedback function.

-Movement analysis:

This section explains all possibilities of rein movements. As shown in figure (3.17a) the one part rein with Ball joint and moved grip movements taken into two axes (right/left ,front/back) rein movement, and(up/down), (left,/right) grip movement ,also shown in figure (3.17b) the two parts rein (rein and Telescopic junction) with ball joint, moved grip and control button movements taken into four axes (right/left, front/back) and (twist left/twist right) rein movement and (up/down) telescopic junction movement and (left/right , up/down) grip movement. Here the difference is mode button has three states and used to distinguish between control, feedback and free (rein without any feedback and control)

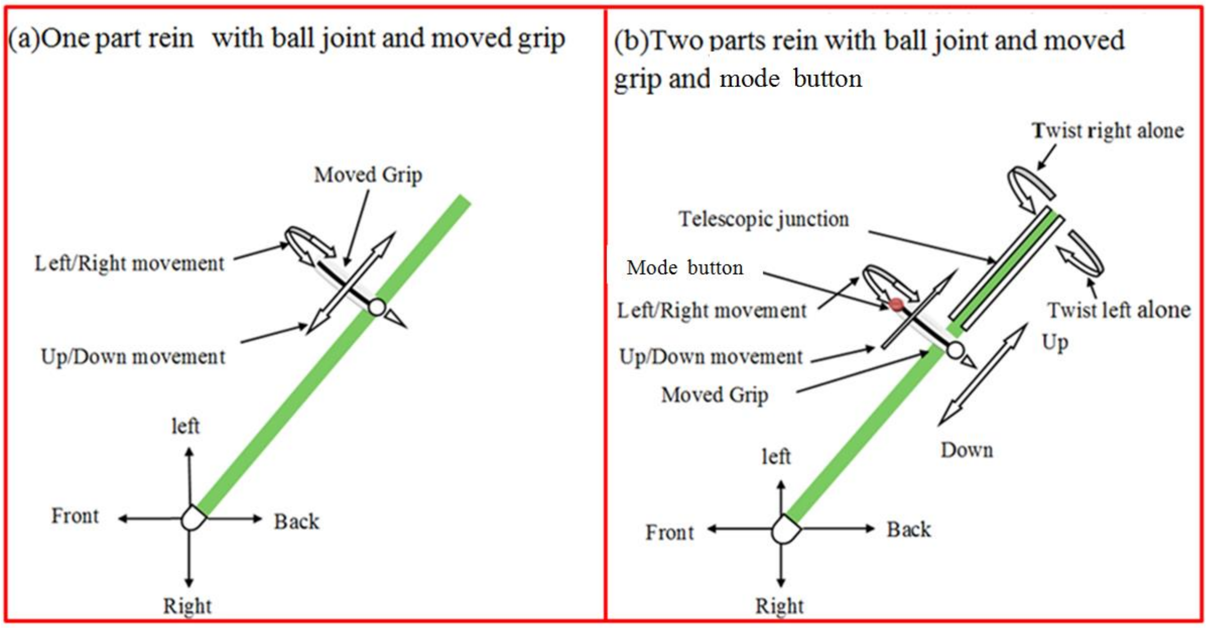


Figure (3.17a, b) (one/two) parts with ball joint and moved grip with (mode button)

3.4.2.4-Movement axes of full movement rein

In general, movements of full movement rein can be divided into number of axes for simplicity of use. These movements are divided into main rein movements, telescopic junction movements and movable grip movements figur (3.18) gives an over view of the movements, the colour indicates group of movements. The movement of the main rein is colour red (front, back, left, right) and it takes axis number one because it's basic movements,

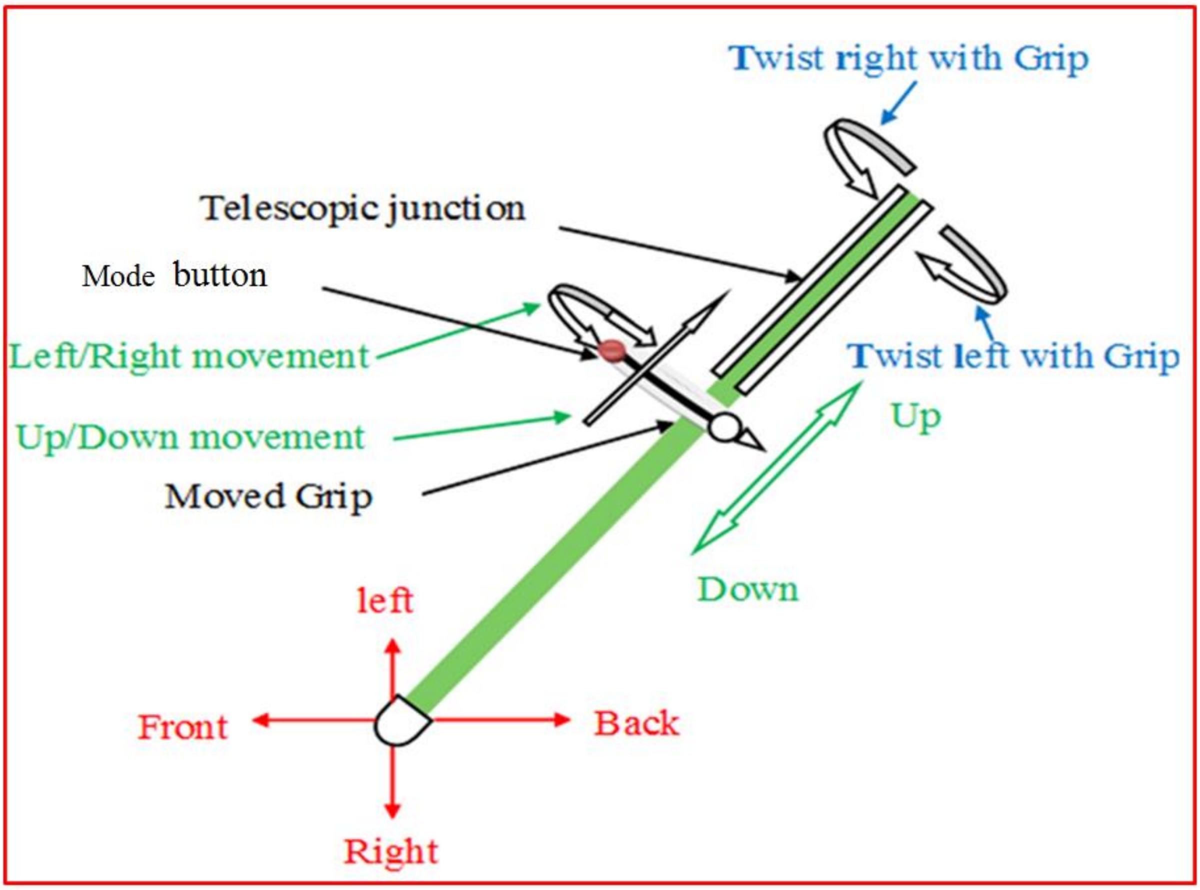


Figure (3.18) Movement’s levels of full movement rein

the movements of telescopic junction colour blue and take axis number two and the movements of grip colour green and take axis number three, as shown in figure (3.18), and table (3.4).

Level one (*Rein*)	Level two (*Telescopic junction*)	Level three (Moved *grip*)
Front	Twist right with grip	Up
Back	Twist left with grip	Down
Right		Right
Left		Left

Table (3.4) Rein movement's axes

3.4.2.5-Movement interpretation

For the reason of design, the interaction between human and robot is divided into three types according to the position of mode button and which has three positions 0, 1, 2. Every position indicates one mode. Mode 0: indicates feedback mode and it means robot/human feedback data (codes) flow. Mode 1: indicates control mode and it means human/robot control commands (codes) and mode 2: indicates free mode and it means the rein is free control disabled. According to this can interpret these (codes) to high-level language to be understood by human and all movement changes to a number of codes which describe specific message. Table (3.5) shows that with details.

Mode button		0	1	2
Type of movement		Robot send feedback to the follower	Follower send control to the robot	Free rein
Front	To rein	follow follower	—	—
back	To rein	go back, follower	—	—
left	To rein	want to turn left follower	—	—
right	To rein	want to turn right follower	—	—

Mode button	0	1		2
Type of movement	Robot send feedback to the follower	Follower send control to the robot		Free rein
Twist right with grip	From Telescopic junction	Can use for other function control		—
Twist left with grip	From Telescopic junction	Can use for other function control		—
up	From Grip	—	go back robot	—
down	From Grip	—	go forward robot	—
left	From Grip	—	turn left robot	—
right	From Grip	—	turn right robot	—

Table (3.5) Rein movement's interpretation

- ***Demonstration of table contents***:

1- When the mode button is 0 the robot sends feedback signals to actuators (motor) attached to the rein for moving in the front side this means clear command for the followe for walking forward.

2- When the mode button is 1 the follower moves the grip down for sending control signals to robot controller to move in forward direction and this means there is a coding table for mutual understanding.

3- When the mode button is 2 robot controller and rein actuators are off. in this case, there is no connection and follower can move the rein without any feedback or control.

3.5-Methods comparison

Table (3.6) shows a comparison of all proposed methods and shows approaches in which to choose the most suitable method for the research. It should be noted that most of the data included in the table is based on estimation. The scale is divided into a high expectation high achievement ratio and low expectation low achievement ratio and medium in between.

Method	Clarity of messages	Easy to learn	Used control/feed back	Enough spectrums	Health impact	Attached with user body	Installation in the university laboratory	Availability of materials	Availability of references
Electromagnetic haptic interpreter cuff	MEDIUM	LOW	LOW	HIGH	MEDIUM	HIGH	MEDIUM	MEDIUM	MEDIUM
Electric pulse haptic interpreter cuff	MEDIUM	LOW	LOW	HIGH	MEDIUM	HIGH	MEDIUM	MEDIUM	MEDIUM
Haptic printer interpreter cuff	MEDIUM	MEDIUM	LOW	HIGH	MEDIUM	HIGH	MEDIUM	MEDIUM	MEDIUM
Full movement rein	HIGH	HIGH	HIGH	HIGH	LOW	HIGH	HIGH	HIGH	HIGH

Method	Experience within the university area	High completion rate	High success percentage	Cost of the material	Presence of the software's	Technological obstacles	Use in future researches	Built on the previous design
Electromagnetic haptic interpreter cuff	MEDIUM	LOW	LOW	HIGH	MEDIUM	HIGH	MEDIUM	MEDIUM
Electric pulse haptic interpreter cuff	MEDIUM	LOW	LOW	HIGH	MEDIUM	HIGH	MEDIUM	MEDIUM
Haptic printer interpreter cuff	MEDIUM	LOW	LOW	HIGH	MEDIUM	HIGH	MEDIUM	MEDIUM
Full movement rein	HIGH	HIGH	HIGH	MEDIUM	HIGH	LOW	HIGH	HIGH

Table (3.6) Comparison of all proposed methods

From the table (3.6) it is clear that the full movement rein is the most suitable for building the research porotype. This can be concluded as the method scores highest within the critical section criteria such as:

- Clarity of messages intensity that can be easily understood by the follower without confusion, easy to learn,
- Lack of a health impact on the follower
- The possibility of installation and testing in the laboratory
- The possibility of experience within the university area
- Availability of materials for the implementation and can be built on the existing design

Additionally, the method naturally provides a simple intuitive system which can work in control mode (from follower to the robot) and in feedback mode (from robot to follower). Moreover, it can be simplified as required and interfaced with the previous design.

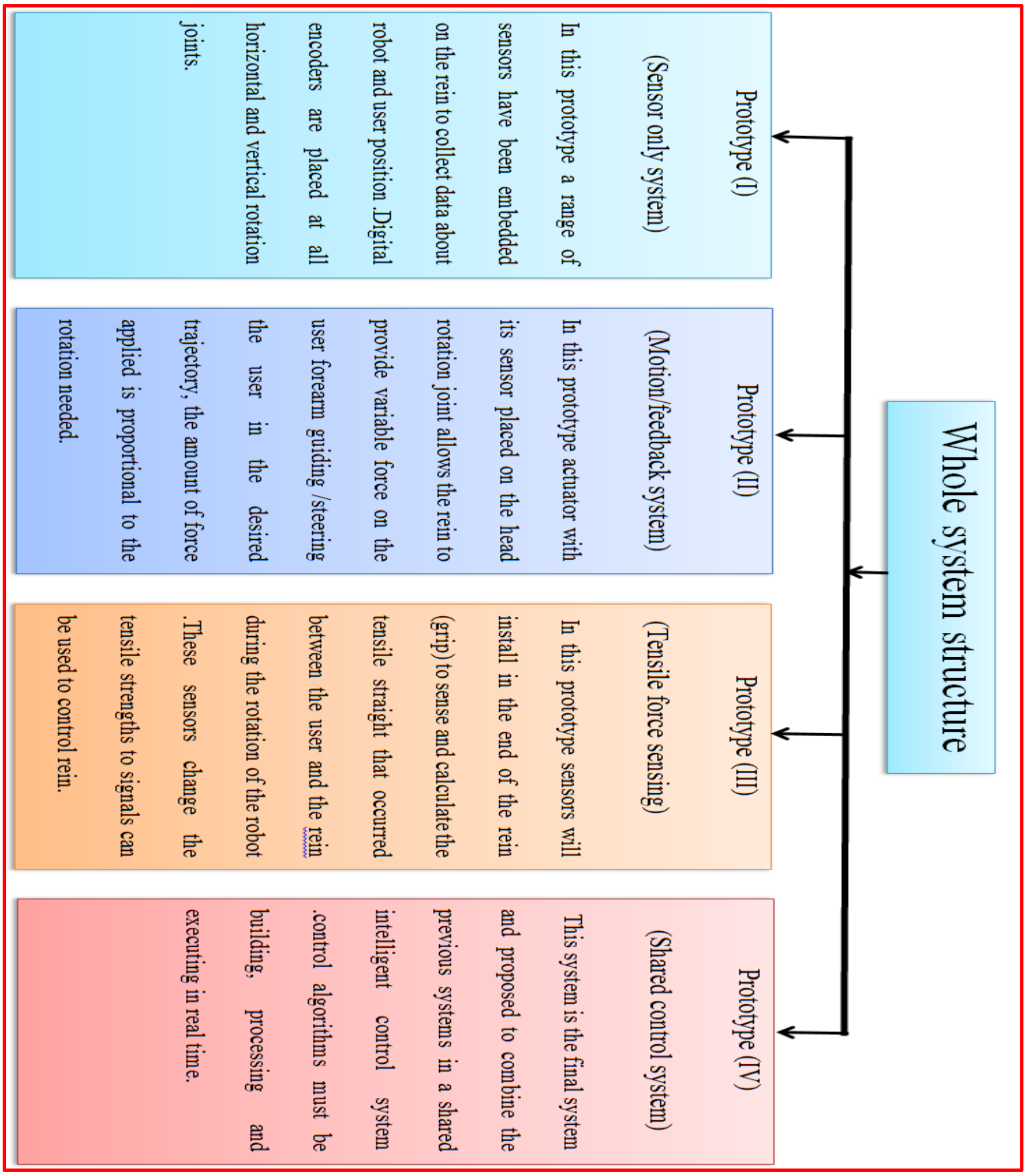
3.6-Proposed system structure

After selecting the use of a full movement rein in the research; the overall design strategy and implementation was assessed and divided into four subsections with separate sub prototypes. Each prototype can be individually designed, built and tested before integration into the complete design making the research implementation and testing easier as shown in the figure (3.19**)**. A plan has been prepared for the requirements of each prototype separately, with appropriate CAD model produced where required to choose the appropriate design and calculate the quantity of materials that to achieve the goals of research with the lowest cost and in a reasonable time.

In the prototype (I) which had a set of sensors (encoders) has been placed in the front edge of the existing rein to know follower /robot location. The prototype (II) had a stepper motor and its encoder, which implement to move the rein and fixed to robot base, the sensor (encoder) has been attached to motor head the function of the motor sensor is to calculate the angle and speed of rotation. The ends of the rein are attached to the motor shaft by using steel rope (it has a small diameter and flexible) so that the rein can be pushed in any horizontal direction and at any required speed as shown in figure (7.6). Prototype (III) has some sensors (load cells) in the grip of the rein to calculate the strength of tensile which occur between the follower hand and the long axis of rein. Depending on the sensor (load cells) readings the motor moves the rein in direction of the follower to make tensile strength low; in that case the follower can follow the path of the robot as much as possible. In the prototype (IV), all previous prototypes will be connected to an integrated system which can move the follower to follow the robot path by sending messages from the robot to the follower in the form of rein movements. Whole system structure is shown in figure (3.19**)**. It is noteworthy for easy study and review a prototype the building has been divided into a set of steps which are repeated with a change in details and these steps are:

- Rein prototype problem definition
- Rein prototype aims
- Rein prototype system building specification
- Rein prototype design

- ➢ Rein prototype implementation
- ➢ Rein prototype test



Prototype (I)
(Sensor only system)
In this prototype a range of sensors have been embedded on the rein to collect data about robot and user position .Digital encoders are placed at all horizontal and vertical rotation joints.

Prototype (II)
(Motion/feedback system)
In this prototype actuator with its sensor placed on the head rotation joint allows the rein to provide variable force on the user forearm guiding /steering the user in the desired trajectory, the amount of force applied is proportional to the rotation needed.

Prototype (III)
(Tensile force sensing)
In this prototype sensors will install in the end of the rein (grip) to sense and calculate the tensile straight that occurred between the user and the rein during the rotation of the robot .These sensors change the tensile strengths to signals can be used to control rein.

Prototype (IV)
(Shared control system)
This system is the final system and proposed to combine the previous systems in a shared intelligent control system .control algorithms must be building, processing and executing in real time.

Figure (3.19) Whole system proposed structure

3.7-Conclusion

It is clear from this chapter, there are many methods used to deliver haptic feedback from the robot to the follower. However, to emulate the follower guide dog relationship the chosen method must have control /feedback ability as the first factor, the second important factor in choosing the appropriate method is the existence of adequate information and materials for the installation and experience inside university laboratory. From previous demonstration full movement rein has the ability to represent the dog follower relationship for that it is the best method, especially in terms of the possibility of installation inside the laboratory, on these bases full movement rein was chosen. The whole system was divided to four prototypes, each prototype has separated test to determine it is suitability. In the coming chapters, each Prototype will be installed on its own and eventually assembled to form the whole shared control system.

Chapter four

REIN PROTOTYPE ONE (SENSOR ONLY SYSTEM)

4.1-Introduction

From undertaking an assessment of all proposed methods in chapter three it was decided that the system would use and implement a full movement rein. The full movement rein was chosen because of its technical capabilities which best suit to the intended application as described in the previous chapter. The system implementation was divided into four separate prototypes as shown in chapter three figure (3.10). Each prototype was tested and verified independently to assess its performance and influence on the follower. The final system combines all the prototypes into the complete intelligent rein device.

In the first prototype, sensors (continuous encoders) were placed at the moving joints of the rein, in order to determine the robot/ follower location (His right-hand location angle from the middle point of robot base). These sensors readings were sent to the computer through the embedded system for processing, LabVIEW program installed in the computer works on receiving and storing data instantaneously and then display the data on a set of indicators which can be tracked and used, thus the robot can find out the location of the follower right hand in vertical and horizontal dimensions.

In this chapter, there is a description of all steps which have been taken to implement the prototype system. Relevant blocks diagrams and schematics to show the prototype hardware components, connections and charts demonstrating the software structure are also provided. Moreover, a prototype test to accurately calibrate the system has been completed which compares real and virtual measurements in order to establish the difference and offset values of the prototype.

4.2-Rein prototype (I) problem definition

In order to achieve clear relationship between robot/follower it is necessary to define a common language, which can be understood and interpreted. In this case, the language is haptic movements which both the guide (robot) and follower (human follower) can send, receive and understand. The forces applied movements to represent control/feedback data. The hard rein acts as the medium through which data is transmitted and received. For successful guidance (movement of the rein) both the follower and robot guide must have an understanding of their relative locations with respect to one another. The challenge of this prototype is how to determine the location of the follower with respects to the robot. The rein is constrained such that the follower may be a maximum of (+90^o, -90^o) degree angle from the central axis as shown in figure (4.1)

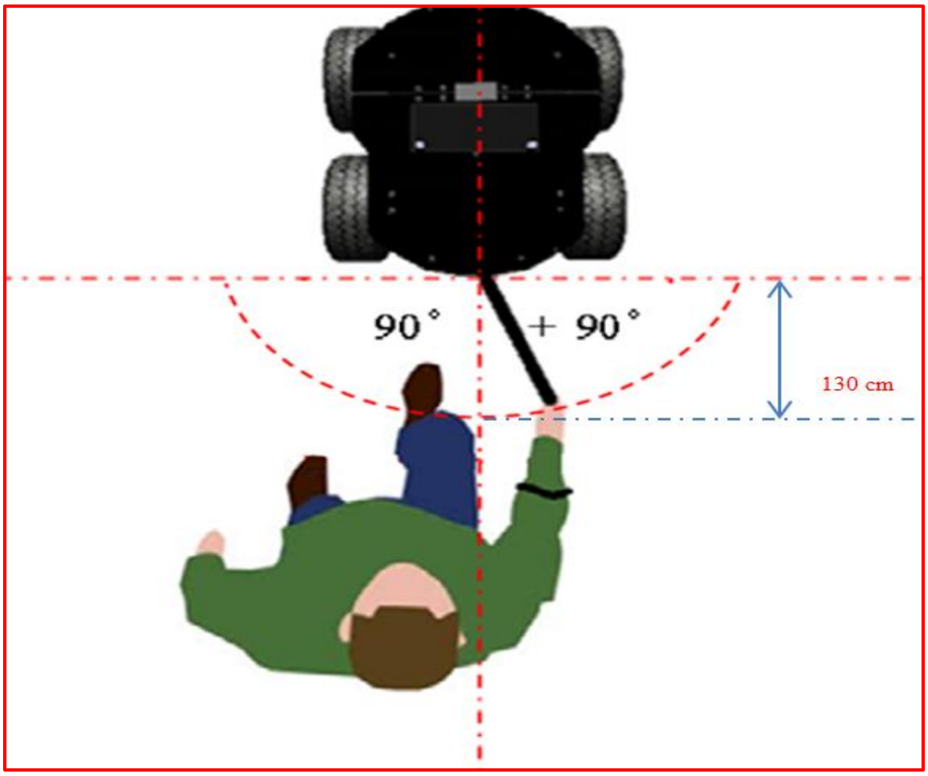


Figure (4.1) Follower follows the robot

4.3-Rein prototype (I) aims

As previously described in the problem definition, the robot must know the precise location of the follower hand who griped the rein in order to send appropriate control data through the rein to achieve that the sensor was planted to track and know the location of the follower horizontally and vertically.

The function of this prototype is to embed appropriate sensors in the rein to collect data about follower location, by specifying rein angles, For example (a) first sensor was placed to get the rotation angle (horizontal angle which indicates the degree of robot rotation) . (b) second sensor to get straight angle (vertical angle which indicates the height of rein from the robot base level).

4.4-Rein prototype (I) system building specification

The prototype system was built to meet specific design criteria including small physical size so it can be put on a small robot surface, simple integration with the previous design, easily mountable on the surface of the robot platform and critically the ability to track the follower movements in the vicinity of 180 degrees shown figure (4.1), at a speed of 0.5 to 1.5m/s (Browning et al., 2006), on the perimeter of the circle has center in the base of rein which installed on the surface of the robot and with radius 130cm. With the possibility of reading, transmitting and analyzing of extracted data from the criteria set, the following design specifications were established; system components and materials were then identified for the design.

4.4.1-Sensors

- Continuous rotary sensor with high resolution to track the follower moving on the circumference of a circle with a radius of 130 cm and follower walk with liner speed of 0.5m/s to 1.5m/s as shown in figure (4.1).
- Small in size and weight, there are many types and sizes of sensors, but this prototype needs small size and weight, because of the robot base, limited in weight load and area.
- Supply voltages of ideally 5.0 V dc/3.3Vdc voltages but for simple integration with the existing hardware.
- Relatively low cost in order to be appropriate for the limited budget reserved to complete the research
- Preferred digital output, to minimize additional circuitry requirements (amplification, filters, ADC) and allow connect with other embedded system.
- Output voltages 0 to 5+ (+/-10%) which can be connected with other digital equipment's has 5V logic
- Appropriate software libraries and/or drivers to minimize the development time and effort

4.4.2-Embedded system

- Operating voltage 5V to be compatible with other digital equipment
- Digital I/O pins to receive data and transmit control signals for the sensors and other elements
- Analog Input to use in receiving direct analog data without using A/D converter
- Compatible with standard PC

- Memory for the store and manipulate data
- Universal Serial Bus host port to connect with PC or other elements
- Low cost, to be appropriate for the limited budget reserved to complete the research
- Suitable size to fit on the robot limited surface area.
- Has wireless utility to be used as an access point with university router if necessary
- UART lines with appropriate data rate and protocol of 7, 8 bits data, stop bits 1, 2 Parity odd, even to be used in selecting R/T data protocol.

4.4.3-Software programs

- Software must have graphical programming language to minimizes the time and effort required
- Easy to build user interface
- Integrated for communication with hardware to interact with system components
- Can be used to create test and measurement, data acquisition, instrument control, data logging, measurement analysis, and report generation applications.
- Applicable in real-time situations. To deal with the parameters such as operating speed.
- Reasonable software cost

4. 5-Rein prototype (I) design

4.5.1-Rein prototype (I) design block diagram

After defining the problem of the prototype (I) which is collect data about robot/follower location and determining the specifications of the most important components. Electronic elements and other components selected to achieve the purpose of the prototype. The EMS22-Non-contacting absolute encoder, appropriate embedded process system NI myRIO-1900, and LabVIEW program, these components met the specification declared previously. Moreover, the appropriate scheme showing the connection points between these elements has been developed. Where the encoder (I) and (II) connected to the NI myRIO port A, as shown in figure (4.2).

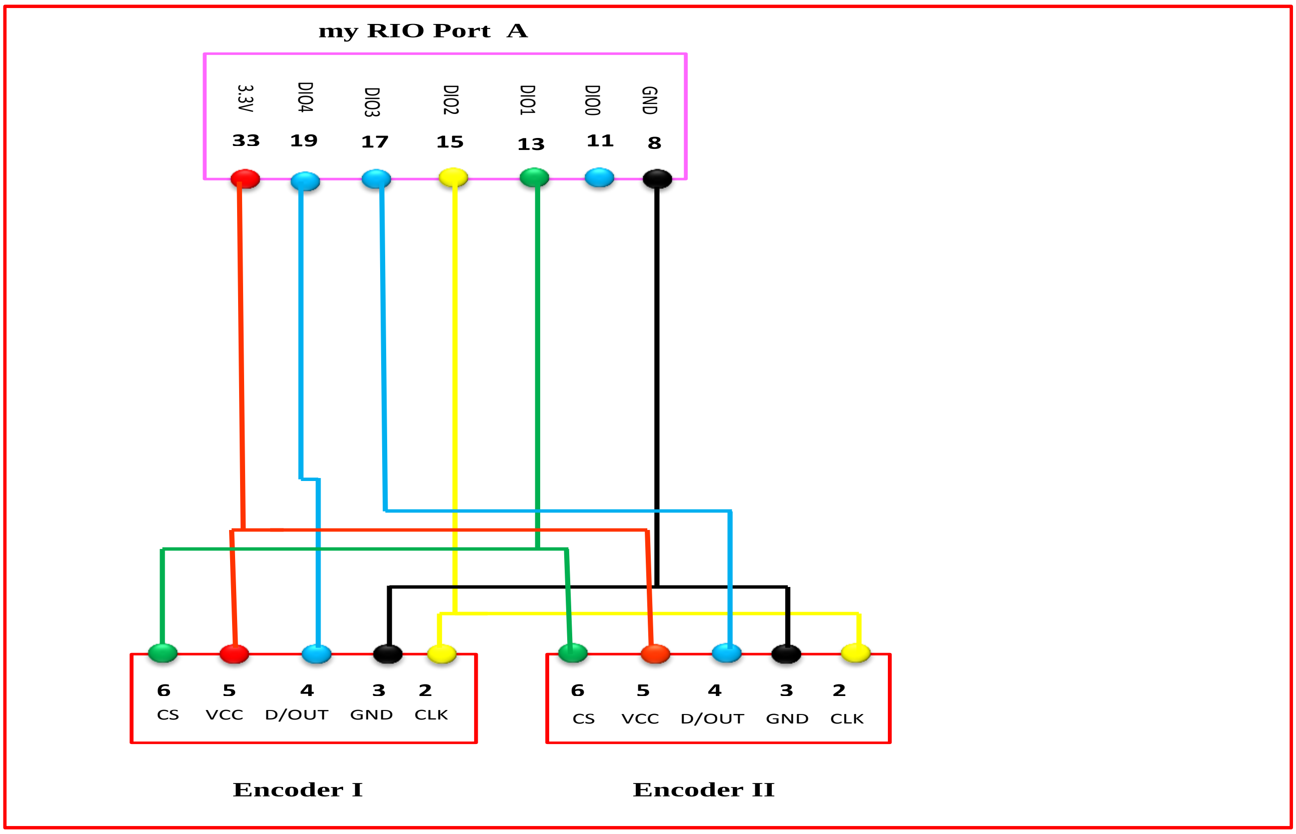


Figure (4.2) Rein prototype (I) design block diagram.

4.5.2-Rein prototype (I) CAD model

A CAD model was created using SolidWorks to visualize and determine the appropriate mechanical design and subsequently help with the selection of the type, dimensions and properties of the required materials. Moreover the CAD model allows easy configuration to test and update alternative designs by check and experiment the model in virtual space and make trails to adapt modify parts and do test for the whole prototype. Furthermore if any error happens in dimension the model can be reconstituted with out any extra cost, figure (4.3) shows the prototype (I) CAD solid work model.

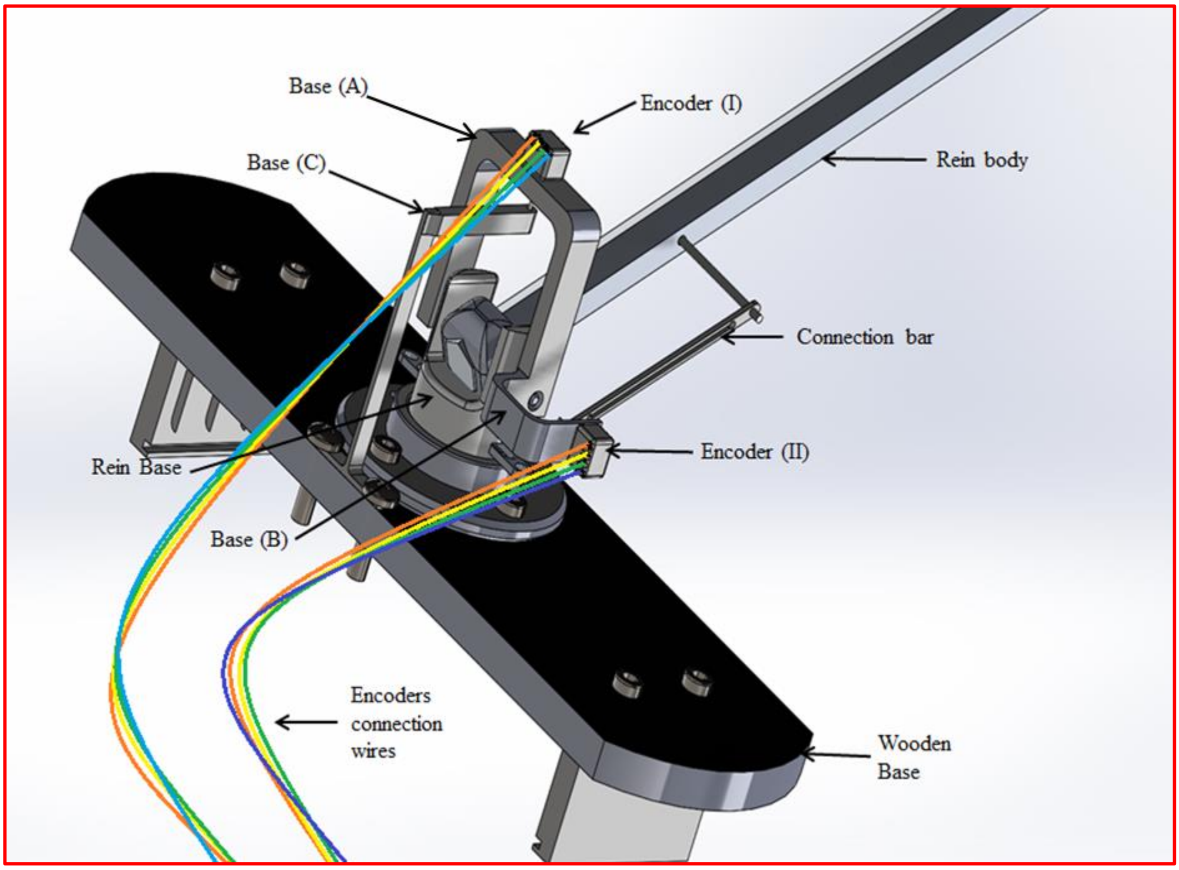


Figure (4.3) Prototype one solid work CAD model

4.5.3-Rein prototype (I) mechanical mounting plates

4.5.3.1-Encoder (I) mounting (metal base (A))

From the review and evaluation of the SolidWorks CAD model, which the major components were identified and a suitable material was selected. Moreover, to mounting the encoder (I), it is necessary to make a metal plate in the shape of a rectangle minus a rib mounted on the rein base. This metal plate will be used to connect and load the encoder (I). With the following diameters length 90mm and width 75mm and thickness 2mm has three holes, first in the top to connect the encoder (I) for following the horizontal movements of the rein with diameter 4mm. Second and third hole on the right and left side with diameter of 4mm, first hole to metal plate rein base connection and the other to fix the metal base (B) with this base, as shown in the solid work model, figure (4.3)

4.5.3.2-Encoder (I) mounting (metal base (B))

After the construction and using SolidWorks CAD model for testing parts and get the perfect design, it became clear that an additional requires to install a small metal plate in the shape of a rectangle minus a rib mounted on the right side of metal base (A) to attach the encoder (II). It has the following dimensions length 40mm and width 25mm and thickness 2mm and with two holes one in the right side to connect the encoder (II) for tracking the vertical movements of the rein with the diameter 4mm and the other on the left side with diameter 4mm to connect this base with the metal base (A) as shown in the solid work CAD model, figure (4.3).

4.5.3.3-Metal base (C)

After the construction and testing of the SolidWorks CAD model, it became clear that it requires the installation of a small metal plate on the shape of letter L (base C)mounted on the wooden base of the rein, the function of this plate is to fix the head of the encoder (I) and it is installed over the rein wooden base with the following dimensions length 80mm and width 40mm(upper side) and thickness 2mm and it has three holes one in the top side to fit the head of the encoder (I) with diameter of 2mm, and the other holes on the bottom side with 2mm diameter to connect the plate in the rein wooden base as shown in the SolidWorks CAD model, figure (4.3).

4.5.3.4-Encoder (II) head rein connection bar

After the SolidWorks CAD model constructed and tested , it became clear that need to install a small metal bar with the following dimensions length 120mm and thickness of 2mm with two openings holes at the ends ,these holes have a diameter of 2mm , one of them attached to the body of the rein and another attached to the head of the encoder(II) to make it able to follow the movement of the rein as shown in the SolidWorks CAD model, figure (4.3).

4.6-Rein prototype (I) implementation

After the design had been completed and block diagram for connection drawn, hardware and software components have been selected to implement the prototype. These components include sensors, data acquisition, input/output interface (my RIO), mechanical interface components plates and processor system. A standard PC in combination with myRIO is proposed as the processing system, all these equipment's interacted with each other to enabling the data acquisition/sensor interfacing, data transfer and subsequent processing of the data to specify the follower location with respect to the robot.

4.6.1-EMS22A-Non-contacting absolute encoder

In this prototype of research, the absolute encoders were used to measure and read vertical and horizontal angles and convert these angles readings to the coded electric digital signals that can be received by myRIO and displayed in the LabVIEW indicators. The selected encoder's specifications are: EMS22A-Non-contacting absolute encoder with a resolution of 1024 positions and can detect positionof follower with minumam speed 0.612R/s and maxiumam speed 0.1837 R/s will be suitable (Browning, et al., 2006), supply voltage 5.0, 3.3 Vdc, supply current 20mA and mechanical angle 360 degrees continuous for this encoder was selected, for more defiles see appendix C, (mouser.com, 2016).

4.6.2-Encoders bases assembling

After encoders bases are joined in rein base, encoder (I)head is tied to base (C) which is connected to the wooden base, and encoder (I)body is tied to base(A) which connected to rein base .when the rein moved to right or left the encoder (I) head is moved and its body is stable in that case any horizontal angle rotation is measured and changed to signal. Also encoder (II) head attached to connection bar which connected to the rein body, an encoder (II) body is tied to base (B), when the rein move up or down the encoder (II) head is moved and its body is stable in that case any vertical angle movement is measured and changed to signal.

4.6.3-Encoder (I), my RIO connection

See appendix (C-1, 2)

4.6.4-Encoder (II) my RIO connection

See appendix (C-3)

4.6.5-Lab VIEW program

This project needs to process data and give control commands, lab view program is the suitable tool for that because can be used in creating a test, measurement data, acquisition instrument control, data logging, measurement analysis, and report generation (Wang et al., 2012). Moreover Lab VIEW is a programming environment which can be used to create programs using a graphical notation, and it is an interactive program development and execution system designed. The LabVIEW development environment works on computers running Windows and has my RIO driver (ni.com, 2017). In this project a lab view program has been devolved and implemented, it is developed for gathering data from sensors (Encoder) and processes this data for controlling the rein movements. Appendix (D) shows the LabVIEW program used in prototype one and it is features.

4.7-Rein prototype (I) test

4.7.1-System start-up

See appendix (C-4), figure (4.5) shows the real system structure.

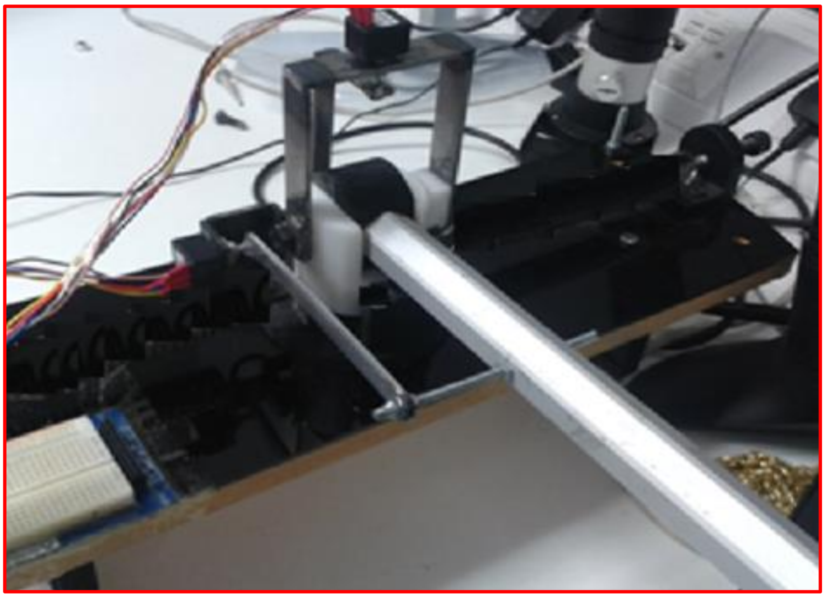


Figure (4.4) Real system structure

4.7.2-Real prototype (I) system test

The encoders, metal plates and hard rein are connected with each other, and encoder's pins connected to my RIO socket via a number of wires. Also, myRIO is powered and USB is connected to PC which has Lab VIEW program, in that case the system is ready for testing. The test program starts by running a lab VIEW program. Moreover, any movement in the rein will move the encoders heads and the encoders convert that movements in to an electric signal received by myRIO and forwarded these signals to be processed and displayed by lab VIEW program (any encoders movement is displayed by lab VIEW analog /digital indicators). To do real system test and get the difference between encoder and manually readings lab VIEW must be running and read encoder scale from the LabVIEW indicator. Moreover it measures the reading by using a special protector, after that cumulative graph can be drawn to explain the difference and the offset value needed to calibrate the system. Figure (4.6) shows the difference between encoder and manually angle readings.

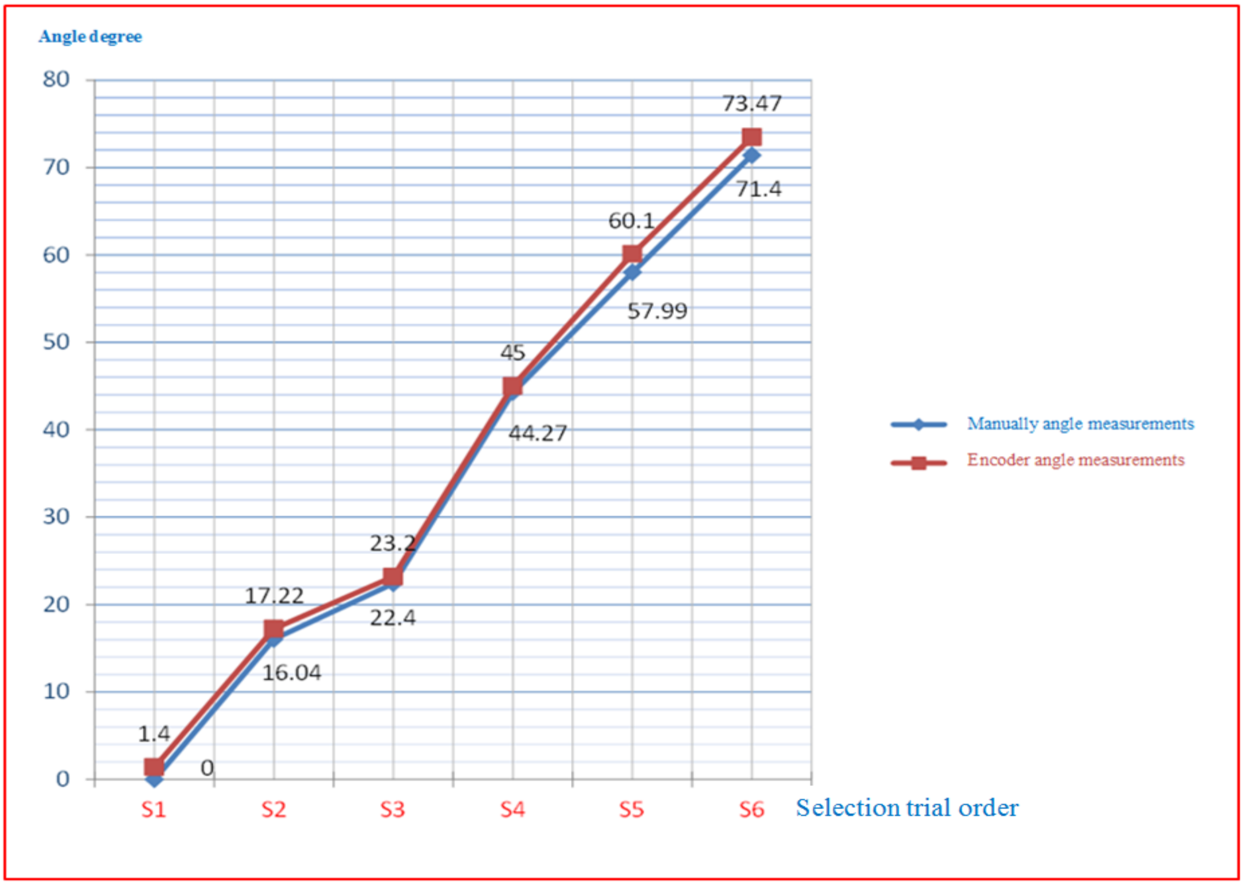


Figure (4.5) Difference between encoder and manually angle readings.

The figure (4.6) shows the difference between the manual angle which is taken by using adjacent and the opposite side (tangent of angle = opposite side /adjacent side) and take inverse to find the angle value and encoder angle which taken form the LabVIEW indicator. It is clear from the figure (4.6) 1.40 degree is the offset value needed to calibrate the system.

4.8-Conclusion

The test on the first prototype shows that the robot can find out the follower's location with great precision in the vertical and horizontal directions. This enables the robot to guide and steer the follower to the desired path after controlling and moving the rein. With this consideration first prototype is suitable to measure the angles and help to indicate the follower position; also, it is reliable to use in the future work as a part of the whole system.

Chapter five

PROTOTYPE TWO (MOTION/FEEDBACK SYSTEM)

5.1-Introduction

The proposed system has been split into four distinct prototypes which will subsequently be integrated to achieve the complete system as discussed in chapter 3. The first sub system prototype (sensors only) has been explained in the previous chapter. The second distinct prototype (motion/feedback system) will be described in detail within this chapter. The main function of this prototype is to provide force feedback between the rein and follower. Actuators will be placed on the rotational joints which allow the rein to provide a suitable force on the follower's forearm guiding/steering the follower to the desired trajectory, the amount of force applied is constant for the rotation needed. The level of compliance/resistance force exerted on the follower from the actuator must be continuously monitored by the control system in order to maintain safe operation.

The purpose of the prototype (II) (motion/feedback) is to steer the follower to the desired path. This has been implemented using a stepper motor with suitable torque to exert a force on the follower guiding him in an appropriate speed and desired direction; also an encoder was placed on the top of the motor shaft to determine the appropriate angle/motor position. The major components required to create the prototype (II) include: a stepper motor, an encoder (sensor), my RIO and motor driver. A range of testing has been undertaken to determine the compatibility of the prototype with the follower and also to know how the follower behaves when interacting with the prototype. The test includes experiments on number of samples to determine the appropriate speed of the motor rotation and torque values in order to achieve safe and effective levels of guidance by the rein.

5.2-Prototype (II) problem definition

In order to achieve the relationship between the follower and guide dog. The prototype (II) will be concerned with how to move the rein in horizontal direction at specific ranges of angles with the maximum of 45° degrees in both directions from the middle point of rein base with a certain speed. The desired range was established from literature, these parameters were used to calculate by a set of mathematical equations, these equations give the minimum and maximum limits as a range of speeds. An appropriate speed will be chosen from the range according to the test result. Figure (5.1) shows rein movement path.

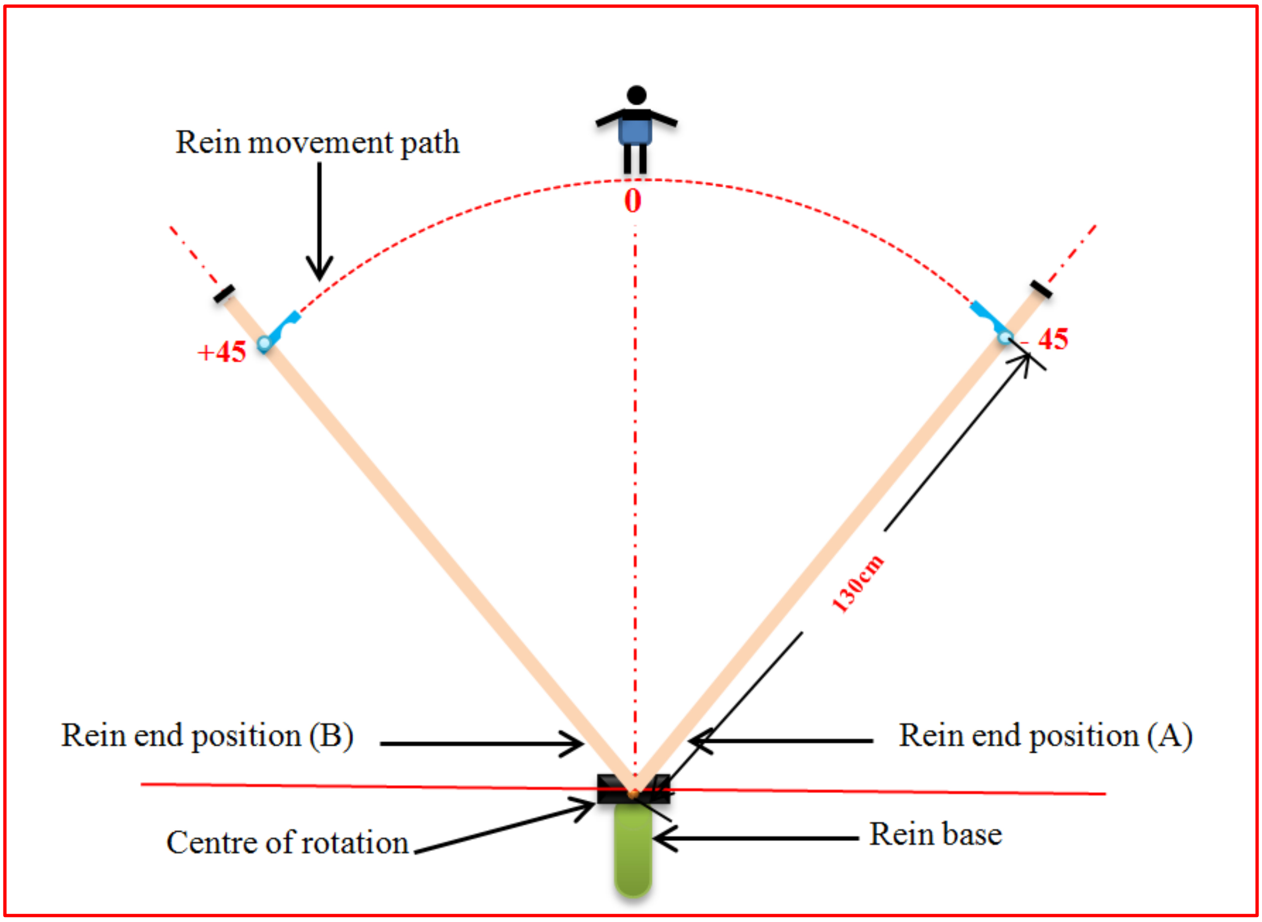


Figure (5.1) The rein movement path.

5.3-Rein prototype (II) aims

This prototype is aimed to place an appropriate stepper motor and encoder to control the movement of the rein in the horizontal direction of the rein base, by using a different range of speed values rotating speed with different values of angles (+45 °/-45°) and test this speed range to select the suitable speed value for the follower.

5.4-Rein prototype (II) system building specification

The system will be built to meet the specifications which include: it can be mounted on the surface of the robot platform as well as its suitability to attach and move the rein in both directions with speed range from 0.5m/s to 1.5m/s linear velocity (*Browning, et al.,* 2006). Figure (5.1) shows that the perimeter of the circle has radius 130 cm and center located in the base of rein which is installed on the surface of the robot.

Other specification of prototype (II) is that it can be connected with the prototype (I). Moreover, it is necessary to look for some extra components in addition to the materials which were already described in chapter 4. In this chapter, the specifications of new materials will be mentioned only.

5.4.1-Motor torque selection test

In order to move the rein gripped by the follower's hand, it is necessary to determine the appropriate and safe levels of torque which must be applied to the following test. Therefore, a force meter (Sauter FK 50) was attached to the rein gripper and participants were asked to hold the rein gripper while the researcher pulls the force meter in the horizontal and vertical axes as illustrated in figure (5.2). The increasing force was applied until the participant's hand moves, and the peak force recorded. This test was repeated for all participants. The conditions of participants are: average age of 32.6 years in the range 30-51 years, height of 1.75m in the range165-180m and the weight of 90 Kg in the range 68-92 Kg.

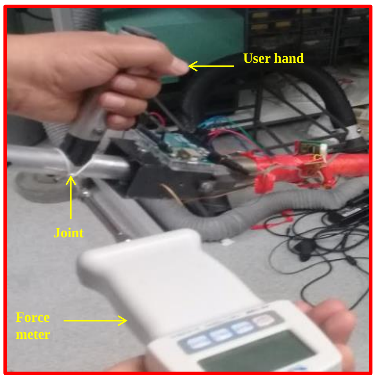


Figure (5.2) Motor torque selection test

5.4.2-Analysis of motor torque test results

After the completion of the test, the data were collected and analyzed as shown in figure (5.3) which demonstrates the relationship between the direction and the force move the follower's hand.

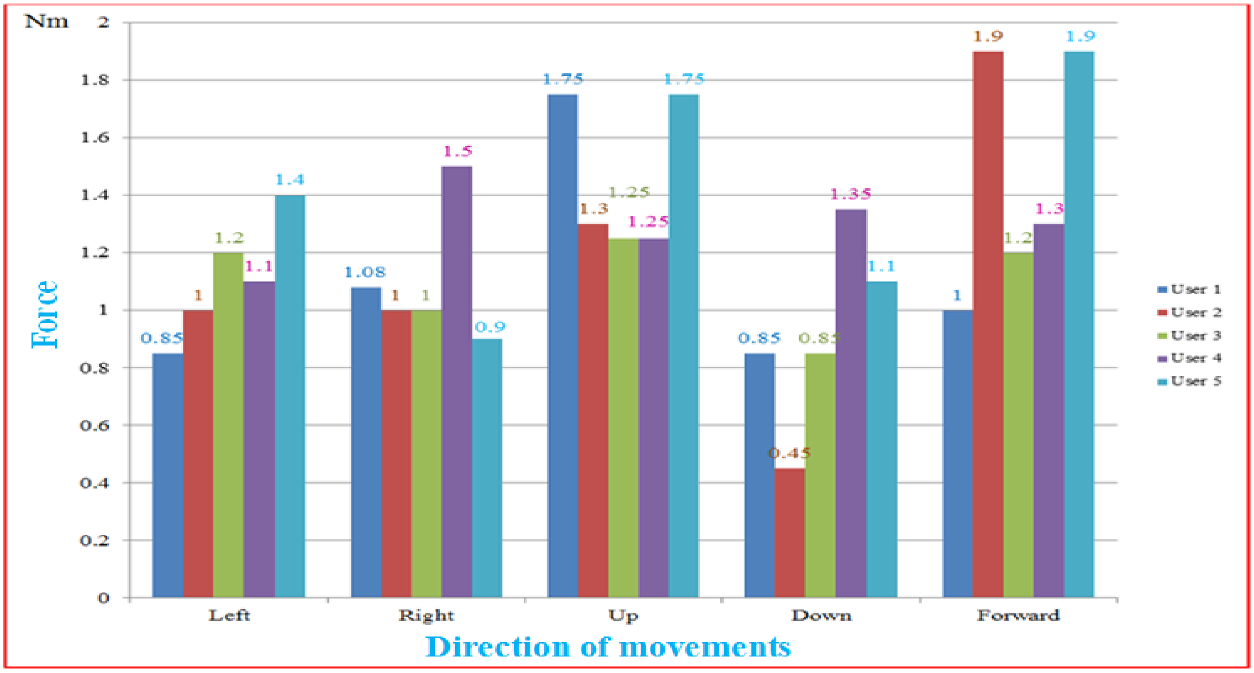


Figure (5.3) Force /direction of movements

To make the relationship more clear, figure (5.4) shows the movement's direction and the average force needed to move the follower's hand.

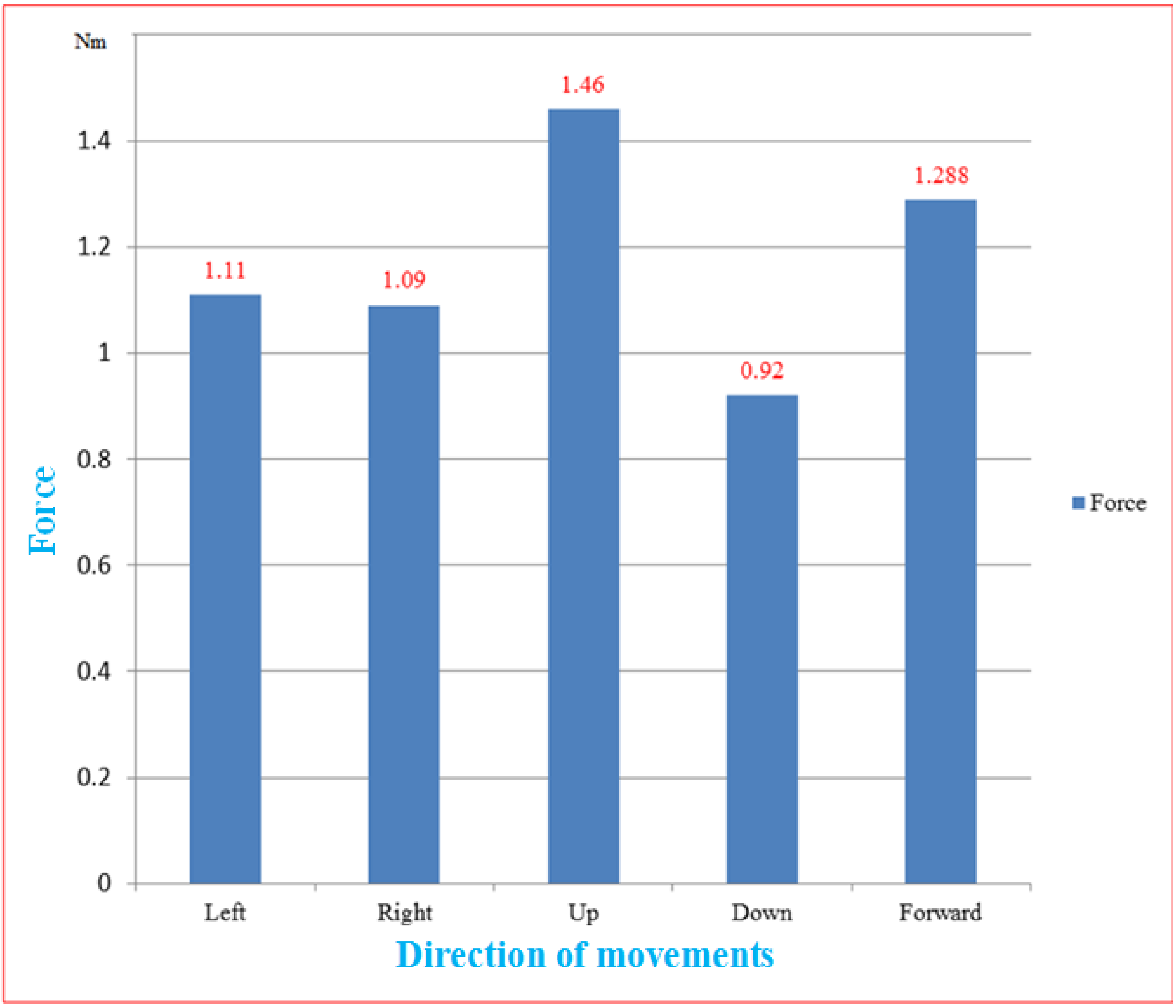


Figure (5.4) Average of force and movements direction

5.4.3-Motor torque test results

From reviewing the previous figures (5.3 & 5.4), it is found that the lowest force required to move the follower's hand is 0.92 Nm in the down direction and the highest force is 1.46 Nm in the upward direction. In this research, just horizontal movement will be used; from the figure (5.4) the maximum force needed in horizontal direction (right/left) 1.11Nm. When the motor is connected to the rein, the focal point is 1300mm from the motor shaft, therefore the resultant total torque required at the end of the shaft (rein) must be calculated according to the formula:

$T = r \times F$ (r = radius, F= applied force)

$T = 1.30 \times 1.11$

$T = 1.443 Nm$

5.4.4-Motor selection

After establishing the required torque, start for looking for suitable DC motor which can move the rein with appropriate speed, there are a number of factors that must be taken into consideration; such as the determination of motor weight, size and maximum speed, the following lists some of the main characteristics:

- Perceivable force applied to the follower.
- The load remains consistent
- Variable low speed.
- Operate with DC power.
- Relatively low cost.
- Has gear to increase torque if necessary.

5.4.5-Motor driver/controller

After establishing the general specifications of the motor such as low variable speeds, fixed low load and will supplied by DC current it was necessary to look for programmable driver to control the motor with variable speed/direction, can connected serial with PC, has number of input/outputs.

5.4.6-Motor & driver selection

After establishing the required torque, size and appropriate weight of the motor, an appropriate motor was selected; in this instance a 23 HSX-306 Geared stepper motor and ST5-Q-NN motor driver. These components met the specifications and test criteria declared previously, for more details, see in the appendix (E).

5.5-Rein prototype (II) design

5.5.1-Rein prototype (II) design block diagram

A schematic figure (5.5) shows the system connections where the motor encoder is connected to the myRIO port A, and the motor driver connected to port B, the speed and direction pin connections and the myRIO channels used for that.

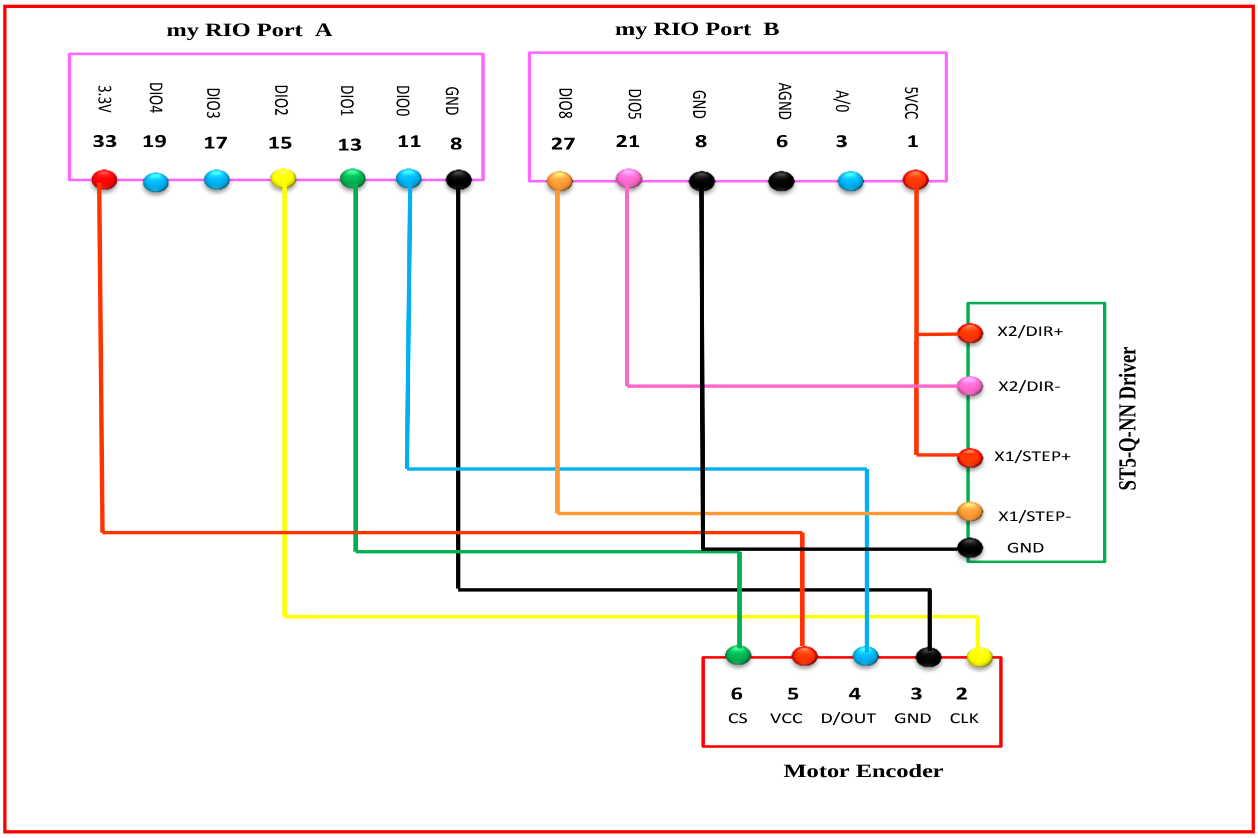


Figure (5.5) Prototype (II) motion/feedback system design block diagram

5.5.2-Prototype (II) motion/feedback system CAD

A CAD package was used to design the appropriate mechanical fixing and housing for prototype (II) as well as to help in the selection of the type of material and establish the dimensions of the materials required. Additionally, the CAD model allows virtual experimentation and easy changes in configuration, figure (5.6) shows the prototype (II) CAD model, where the stepper motor and sensor attachment to the metal plate.

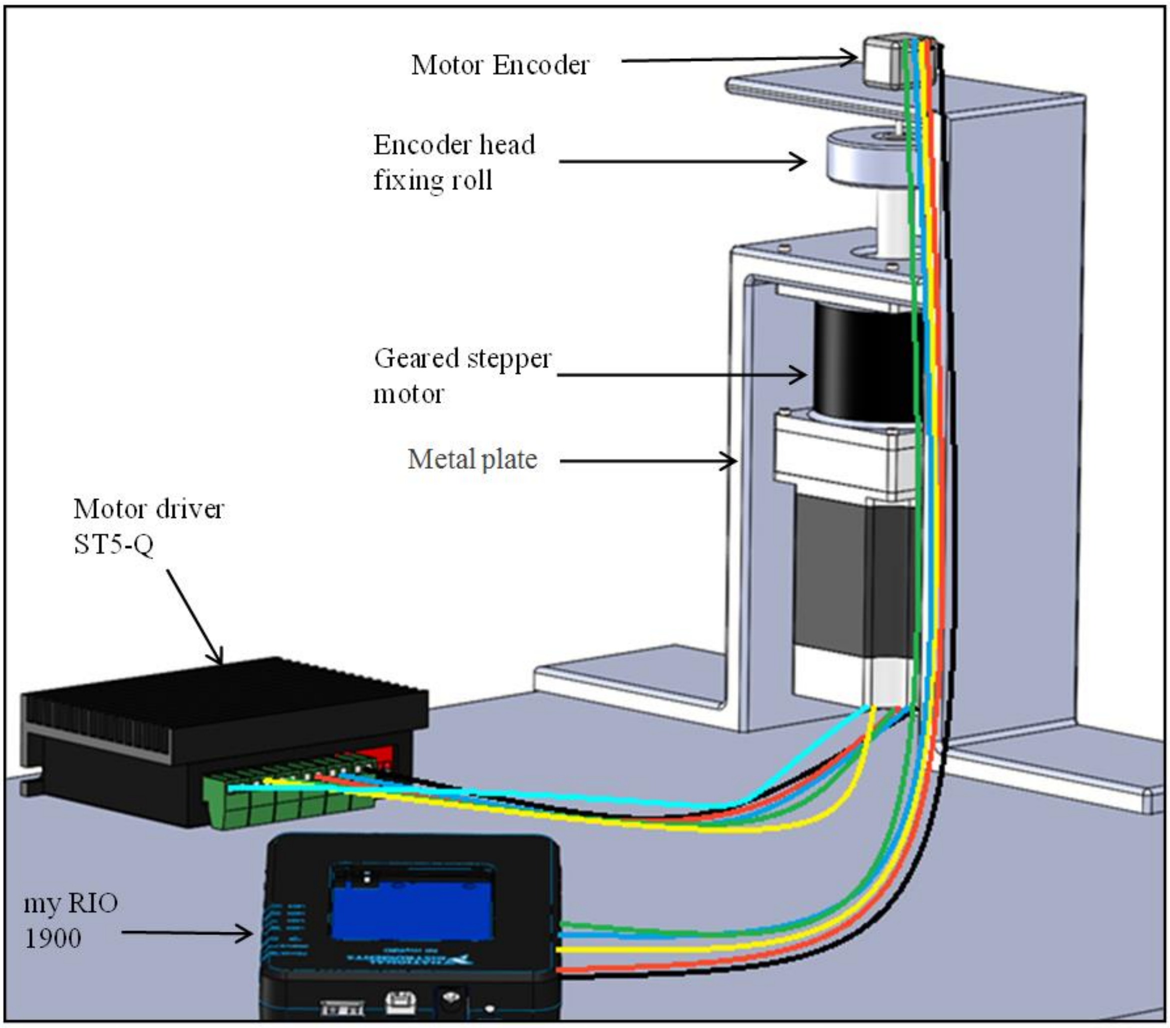


Figure (5.6) Prototype (II) motion/feedback system CAD model

5.5.3-Motor/encoder mounting plate

After the design of system is completed and the test of the CAD model finished, it becomes clear that it needs a metal plate to attach the motor and it's encoder with the described dimensions where one small hole on above to connect motor encoder and big medial hole to connect stepper motor and two holes in bottom to fix metal plate to robot body. Figure (5.7) shows motor fixing metal plate left; right motor installed.

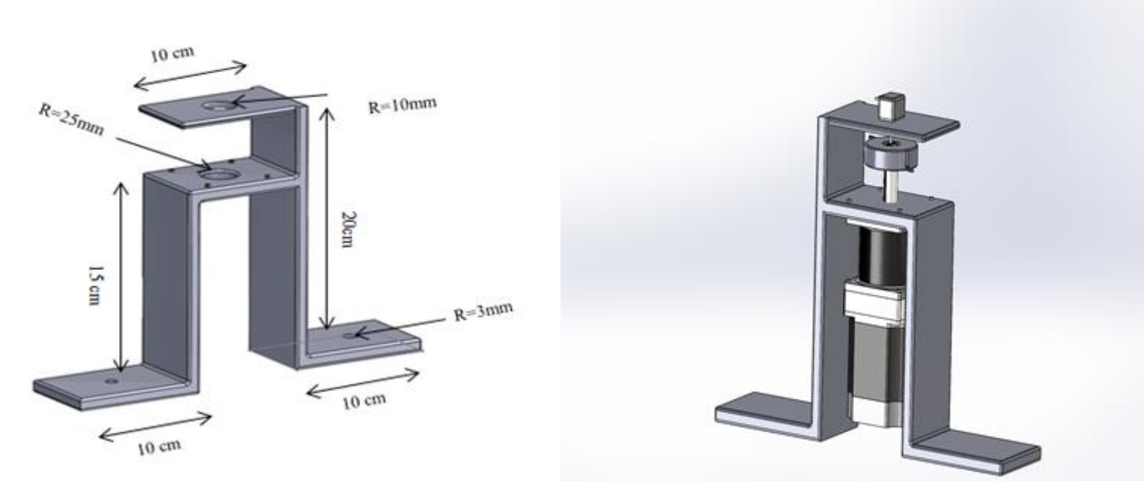


Figure (5.7) Motor fixing metal plate left; right motor installed

5.6-Rein prototype (II) implementation

After the CAD model was completed and block diagram for connection has been drawn, a hardware and software components have been selected to implement the prototype (II) motion system. These components include stepper motor, sensor, mechanical interface components plate, and standard PC in combination with myRIO was used as the processing system. All these components and subsystems are connected with each other to achieve a specific goal, the following sections explain the system implementation steps.

5.6.1-Attaching stepper motor to the metal plate

In order to make the stepper motor usable and stable when moving the rein, the motor was installed on a metal plate which could then be fixed on the surface of the robot; the motor must be stable and have minimal vibration which could interfere with the rein movements. Figure (5.7) right, shows how the motor installed on the metal plate.

5.6.2-Connecting steppers motor with the driver

See appendix (F-1), figure (5.8), specifically in this case the driver is connected to the motor in parallel by 4 wires (A+/A+), (A-/A-), (B+/B+) and (B-/B-) of the motor.

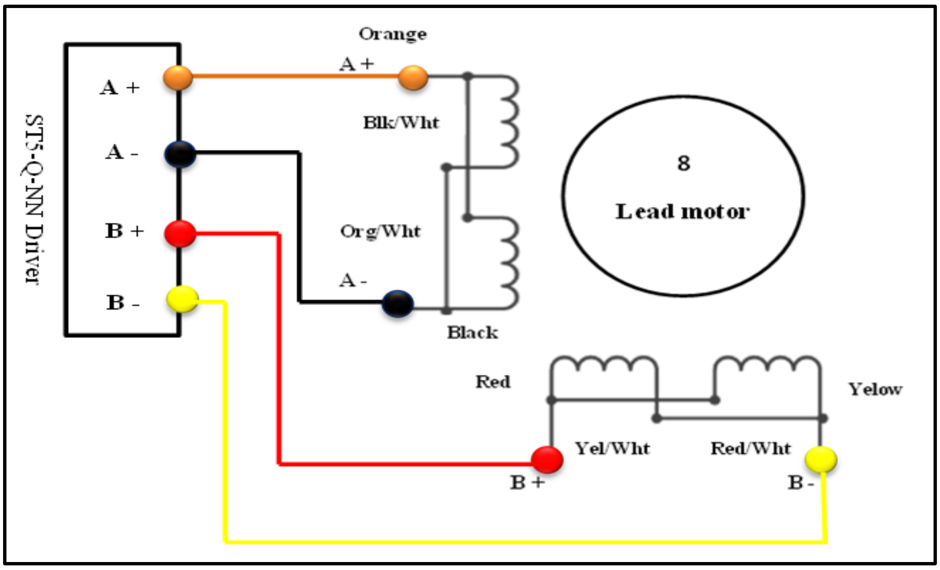


Figure (5.8) Motor driver connection

5.6.3-Connection Motor driver to myRIO (Port B)

See appendix (F-2)

5.6.4-Motor Encoder my RIO (Port A) connection

See appendix (F-3)

5.6.5-ST5-Q driver settings

To configure the motor for the application in order to make the stepper motor move at different speeds and bidirectional, it was necessary to download and install ST driver configuration. The connections from the motor to the ST5-Q driver is shown in figure (5.8). It was also necessary to change the settings to fit the stepper motor use, then the motor is ready to be used over all the speeds and directions required, settings needed to fit for micro steps such as rated current is set to 4.4Amps, holding torque is set to 1.6Nm and rotor inertia is set to 0.34 kg cm^2((McLennan, 2018).

5.6.6-LabVIEW program

This prototype needs to provide commands for the motor to change speed and direction according to processed data coming from the sensors. To achieve this LabVIEW program has been developed. LabVIEW was chosen for the following reasons: Ease of use, speed of software development availability of hardware drivers and interfaces suitable for general robotics sensing and control.

5.7-Prototype (II) test

5.7.1-Starting system test

To start the prototype motion system test, a sequence of actions must be followed. These actions start by system hardware connection such as a sensor, metal plate, motor, ST5-Q driver, myRIO. Then the myRIO is connected to power and PC host computer by USB. Furthermore, the myRIO is connected to power and PC host computer by USB. Another stage in software side starts by running lab VIEW program to identify myRIO to send control signals to the motor. The figure (5.9) and (5.10) show a command flow diagram and the complete real system test has been connected respectively.

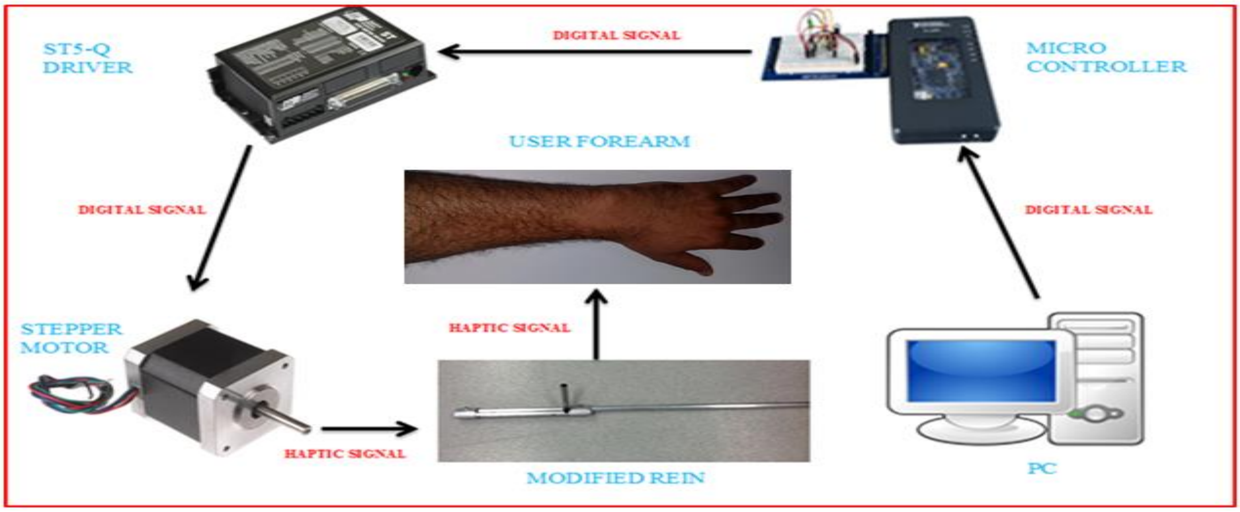


Figure (5.9) Command flow diagram

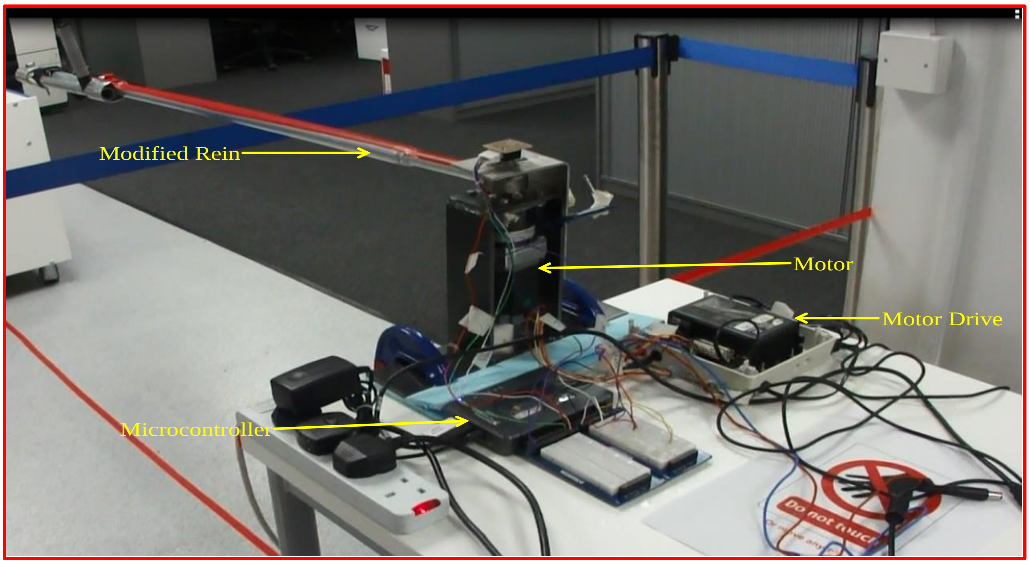
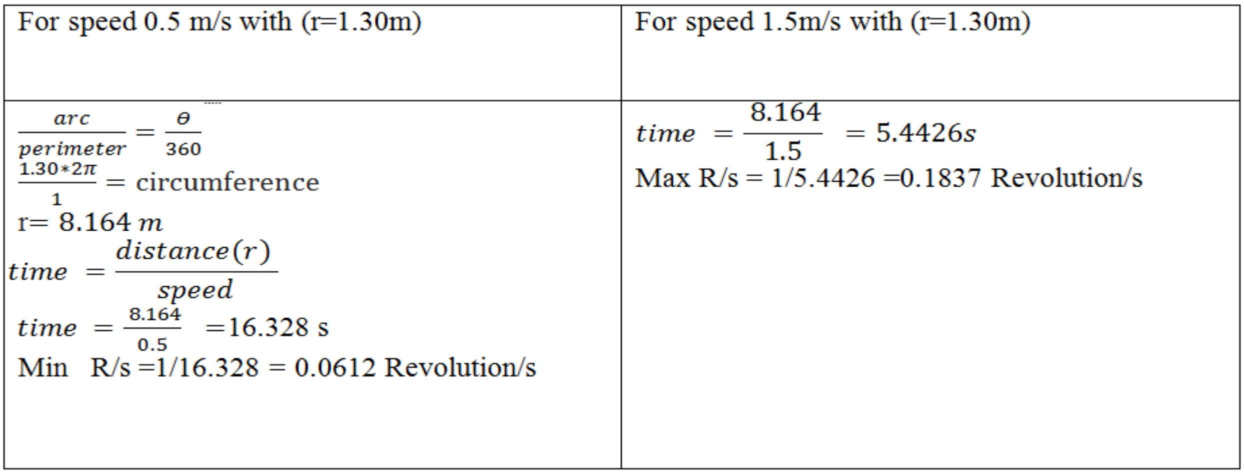


Figure (5.10) Real system structure

5.7.2-Prototype (II) test methodology

The aim of the test is to select the appropriate speed for the follower when the follower moves in the circumference of a circle with radius of 1.30 with the minimum speed of 0.0612 Revolutions /second and a maximum speed of 0.183 R/s. The test sequence starts by executing the LabVIEW base control program; this sends commands to the motor via the myRIO. The motor starts movement in both directions with different speed and the motor encoder moves related to this movement. The function of the encoder is to measure the rotation movement and converting it to an electric signal which can be received by myRIO and subsequently to processed and displayed by PC using the LabVIEW program (any encoder movement can be shown and tracked by the developed LabVIEW software via the associated Analog/Digital indicators).

To start system test and specify the suitable speed for movements as shown in Figure (5.10), the test starts from the theoretical analysis of mathematical equations as shown in the table (5.1), the function of the mathematical equations is to change the linear speed to angular speed and decide the limits of motor revolution speed suitable for a normal human.



For speed 0.5 m/s with (r=1.30m)	For speed 1.5m/s with (r=1.30m)
$\frac{arc}{perimeter} = \frac{\theta}{360}$ $\frac{1.30*2\pi}{1} = \text{circumference}$ r= $8.164\, m$ $time\ = \frac{distance(r)}{speed}$ $time\ = \frac{8.164}{0.5}$ =16.328 s Min R/s =1/16.328 = 0.0612 Revolution/s	$time\ = \frac{8.164}{1.5}\ = 5.4426s$ Max R/s = 1/5.4426 =0.1837 Revolution/s

Table (5.1) Mathematical equations

5.7.2.1-Prototype (II) test procedure

The participant's ties the wrist strap connecting the rein to the participant right hand forearm (in all tests just right-hand forearm used) and puts on a blindfold as shown in Figure (5.11). With each participant, the researcher explains the experiment in terms of the method and the purpose. For example, how participant starts and follows the rein and the number of tracking trials and in any direction and what questions to answer. The participant can request a retry in case of non-discrimination, and he/she may take an attempt before the actual test begins. The researcher starts the test and rotate the rein in the right direction 45° and turned it back to the zero point, after that researcher ask participants if the speed was high, medium or slow and repeat this for all speeds (0.192,0.115, 0.0827,0.0637 Revolutions /second).

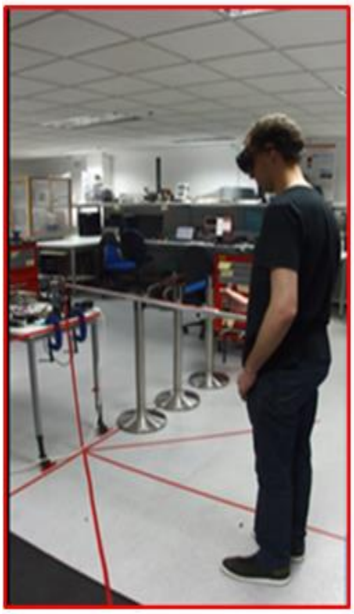


Figure (5.11) One participant attached the rein in the prototype test

The researcher noted the results every time and asks the participants whether they have any suggestions for developing the system. The same procedure was repeated on the left side in for all participants. The number of collected data was 40 samples for both sides. After the practical application, the hesitation of the participants in the answer and their inability to distinguish the speeds were noted, as well as the dispersion of the test data and the lack of correlations, where the collected data distributed for all table and cannot give any specific indicator, for example in table (5.2), (5.3) almost all of the table cells were selected by participants. The table shows speed, how many participants select (slow medium, high) from the five samples, for that requires to change the test procedure.

Speed (R/s)	0.192	0.115	0.0827	0.0637
Slow	0/5	1/5	2/5	3/5
Medium	1/5	2/5	3/5	1/5
Fast	4/5	2/5	0/5	1/5

Table (5.2) Right test

Speed (R/s)	0.192	0.115	0.0827	0.0637
Slow	0/5	0/5	1/5	3/5
Medium	1/5	3/5	4/5	1/5
Fast	4/5	2/5	0/5	1/5

Table (5.3) Left test

5.7.2.2-Updated procedure

As the previous test method gave unclear outcomes an enhanced test method was used. In this test method the researcher told the participants that the test will be in four consecutive speeds and the participants must set the speed that is the most suitable for him. For example, the researcher moves the rein in the right direction 45°and returns it back to the zero position and repeated this for all the speeds (0.192, 0.115, 0.0827, 0.0637 Revolutions /second), and then researcher ask the participants any of the speeds are more appropriate for them and if they have any suggestions for further system development, then the researcher repeats the same test on the same participants in the left direction with the same way and repeats the same question. In this test, the clarity and ease of testing for the participants were noticed and there was no confusion.

5.7.2.3-Alternative test data collection

This test uses the updated procedure, and test data was collected in its second form and placed in a table, compared and figured. It is thus apparent that speed 0.115 Revolutions /second is the most suitable for participants which consist with the mathematical equations results and table (5.4), (5.5) confirm that.

Speed (R/s)	0.192	0.115	0.0827	0.0637
Person/total	0/5	4/5	1/5	0/5

Table (5.4) Right alternative test data

Speed (R/s)	0.192	0.115	0.0827	0.0637
Person/total	0/5	4/5	1/5	0/5

Table (5.5) Left alternative test data

5.7.2.4-Alternative test data analysis

- The participants follow the path from 0 to 45° in both directions with a little deviation as shown in figure (5.12).
- Most participants feel conformable and adapt the test quickly.
- The most important note that most participants choose speed 0.115 Revolutions /second as the best speed in both directions as shown in Figure (5.13) on page 97
- It is noted that most of the participants reach the end line at the 45° and 0 angles in both directions.

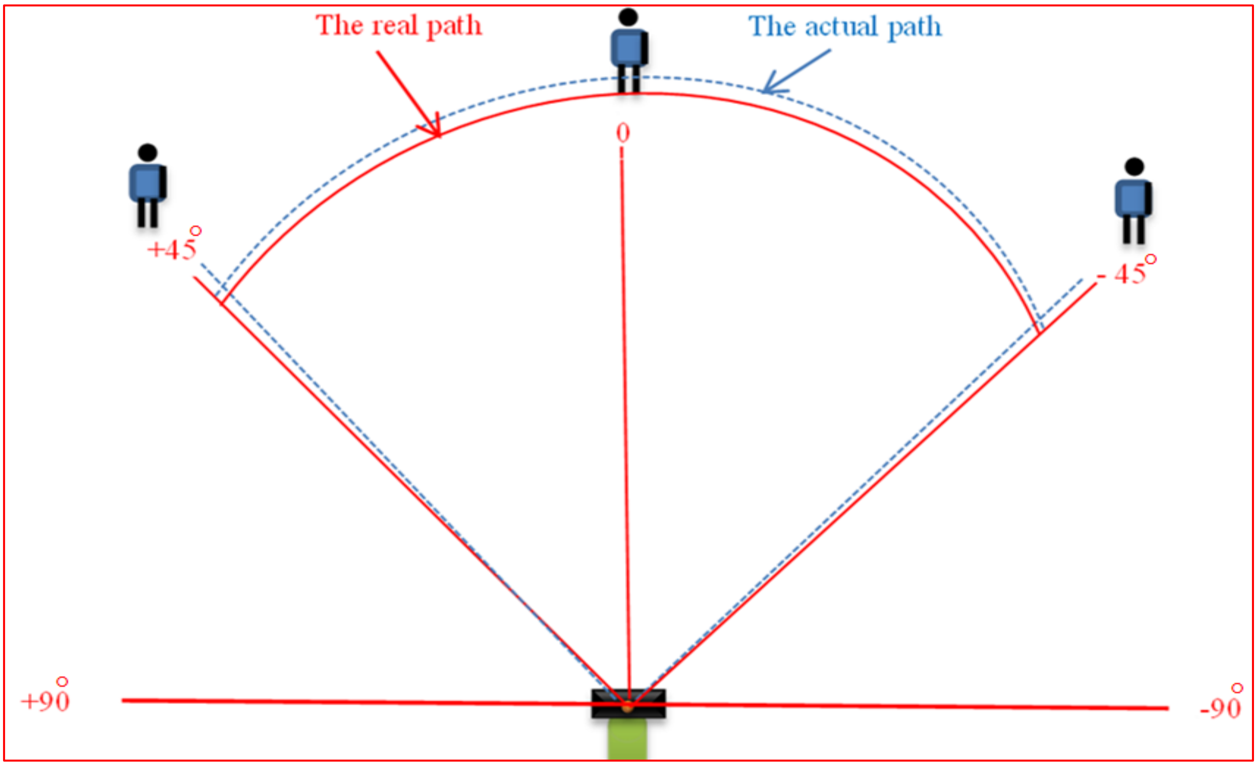


Figure (5.12) (Real/Actual) Path

- It is also noticed that the participants do not have to fasten up the rein which moving in high speed and causing the rotation of the motor without the rotation of the rein and this is called by the researcher as empty step .Or in a clearer sense the stepper motor tray to move without moving the rein, this happens at high speeds such as 0.192 Revolutions /second.
- There are some participants have made proposals for system development. For example, one of the participants suggested that the speeds may change gradual from low to high speed, so this increase the ability of the participant to distinguish the best speed and improve the test procedure.

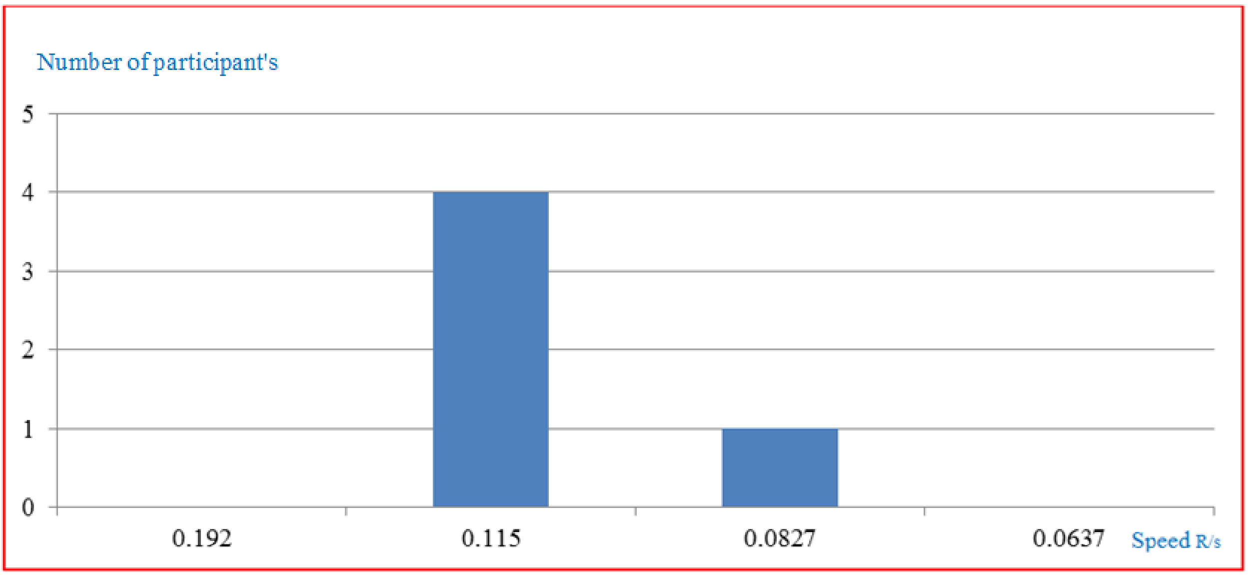


Figure (5.13) Speed selected by of participant's in right/Left direction

- It is worth mentioning here that the LabVIEW programs and system structures have worked satisfactorily as the researcher expected.
- It is noticeable that changing the speed during one attempt negatively effects on the participants because it loses focus on the suitability of the current speed.

- By tracking all results of the data in both directions it becomes clear that the feeling of the participants by speeds in the right-hand side is equal to the feeling of speeds in the left-hand side.

5.7.2.5-The alternative test result

By tracking the results and suggestions of the participants and through the practical observations, have demonstrated that the updated system test is better and its results are very logical and the system is excellent in terms of programs, hardware and can be relied on in the future. The results of the practical test are very close to the theoretical analysis where the speed is chosen close to the midpoint of the distance between the maximum and the minimum speed.

5.8-Conclusion

The test on the second prototype indicates that the system can move the follower's in the horizontal direction. This enables the system to guide the follower to the desired path by controlling and moving the rein. With this consideration, it is reliable to use in the future work as a part of the whole system. The forthcoming coming chapters will explain how the prototype will be installed and assembled to form the complete shared control system.

Chapter six

REIN PROTOTYPE THREE (TENSILE FORCE SENSING SYSTEM)

6.1-Introduction

In the previous chapter, the prototype (II) allows moving the rein in the horizontal direction by range of the angle from 0° to 45° in both directions and with suitable tested speed. This chapter focuses on prototype (III), which is related to embedding of sensors to measure the tensile force that occurs between the follower hand/arm and the rein during the robot rotation and sending control signals to motor to adapt follower movements.

In this chapter appropriate sensors will be selected and a mechanical CAD model will be developed to house the system components and allow the mounting of sensors at specific joints of interest.

After installation, the prototype was tested to be reliable when the whole system is fully assembled. These tests include examining the sensors responses, transfer of the data and the newly created LabVIEW program. The recorded data from the sensor transferred via wireless to flash memory storage.

This chapter will be divided into several parts relating to the sequence of work undertaken. The conclusions obtained from the tests of this prototype will be taken into consideration when building the complete system.

6.2-Prototype (III) problem definition

In the case of the mobile robot turning, the rate of change in rotation at the rein interface may too fast for the follower, causing a level of discomfort if the force exceeds a certain level and additionally pushing the follower outside the safe path. Figure (6.1a) shows the current path during a rotation and figure (6.1b) shows the preferred path.

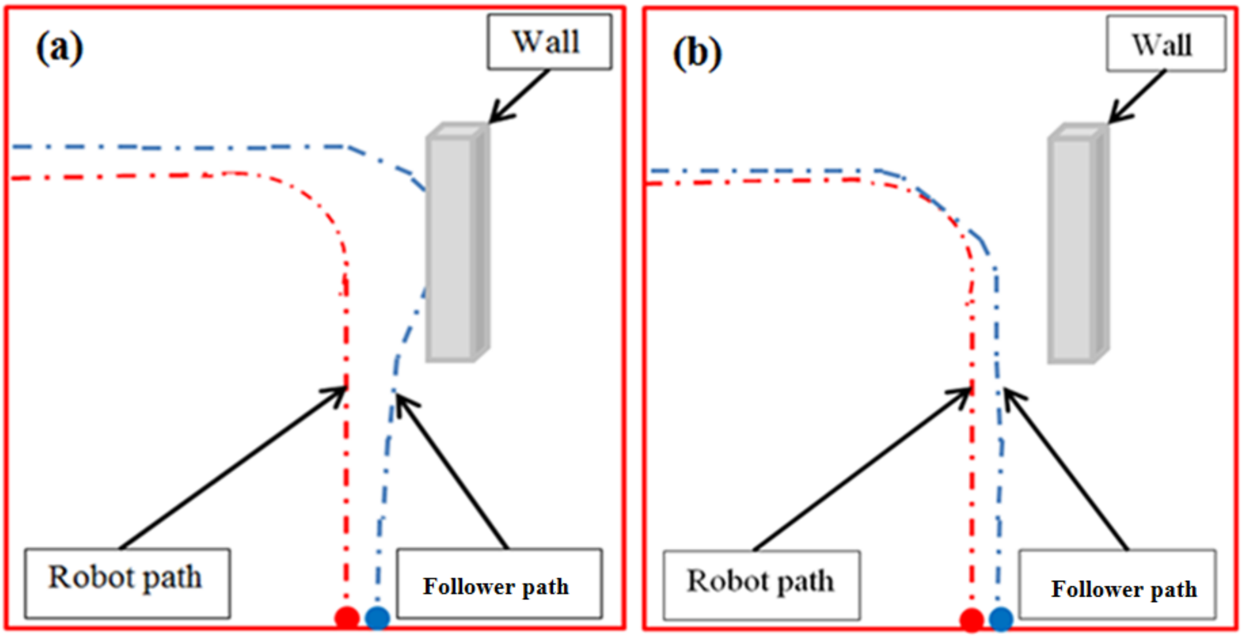


Figure (6.1a) The current path during rotation, (b) The preferred path

This leads to a deviation between robot and follower paths. To make the movement of the follower as comfortable and natural as possible the rein should reduce this difference.

6.3-Rein prototype (III) aims

The main aim of using prototype (III) is to embed a range of sensors to measure the tensile force which exists between follower's hand and the axis of the rein. The measured sensor data must then be transmitted for processing and subsequently used for control of the rein movements which leads to a reduction in the difference between follower and robot paths. Another method can be used by make gloves that can record the pressure between the follower's hand and the fixed grip and convert it into electrical signals control the movement of the motor. As well as can make the base of the rein moving and use the tensile of movement as output to control the motor movements.

But the first method is preferred because of the ease of implementation and the accuracy of the results where the force of tensile strength can be recorded

6.4-Proposed method demonstration

This method can achieved by making the handle (rein grip) move horizontally within limited constraints of ±5° in a controlled response proportional to the combined requirements of maximizing the follower comfort, and minimizing the deviation. Figure (6.2) shows maximum tensile strength &figure (6.3) shows minimum tensile strength. The small amount of flexibility ±5 degrees allows the sensors to detect a change but is not perceived by the follower.

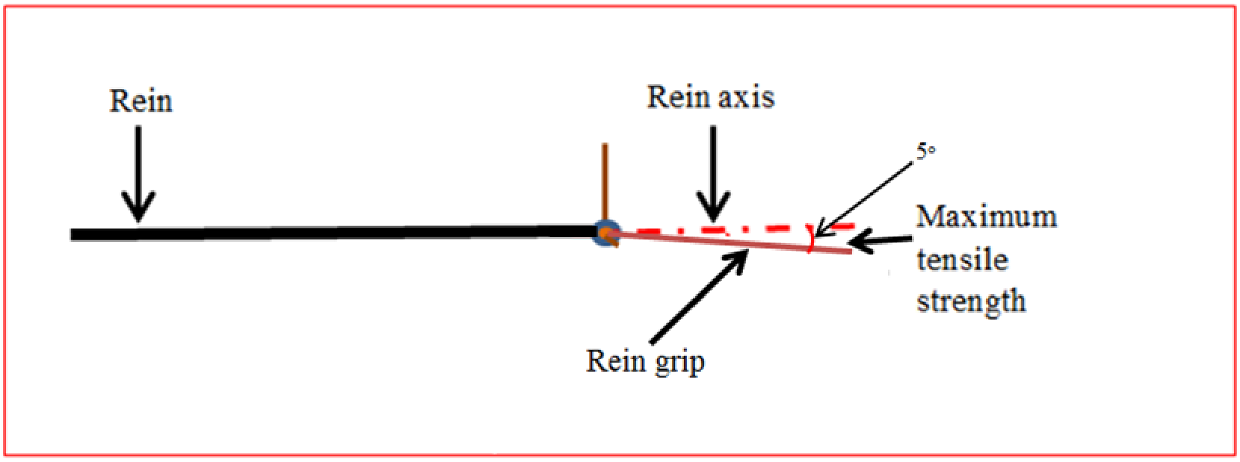


Figure (6.2) Maximum tensile strength

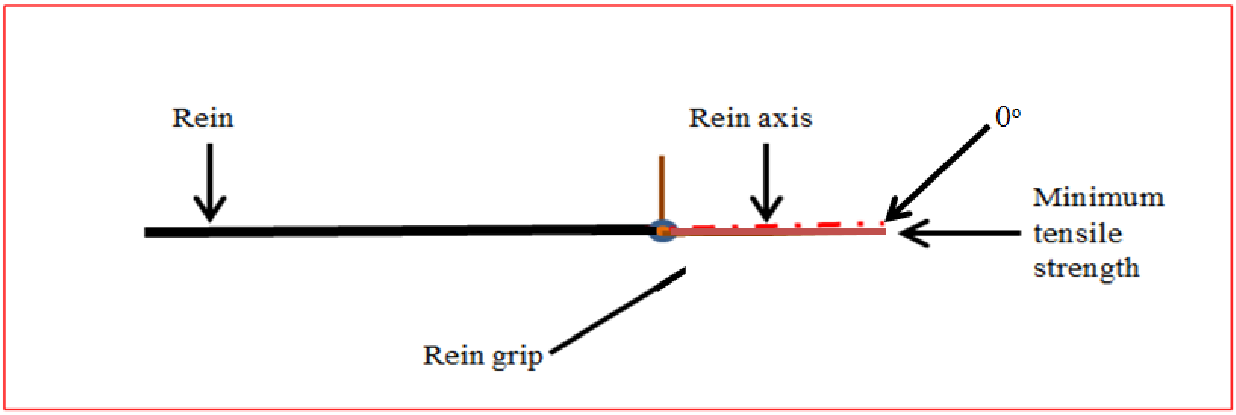


Figure (6.3) Minimum tensile strength

To achieve the control response required it is necessary to know the tensile strength at the follower /robot interface (hand gripper when the robot turns).

6.5-Rein prototype (III) system building specification

The prototype (III) will be built to meet the required specifications which include small size (25 cm x 20 cm) that can attached to the end of hard rein as well as its ability to permit the rein grip to move in both directions with range of ±5°. Also can measure the tensile strengths which occurs when the rein grip deviate from the axis of the hard rein. To solve the problem identified previously and create the prototype with the pervious specification; it is necessary to looking for some new materials in addition to the previous materials which already have been used. Most of these used materials are mentioned in the previous chapters. The specifications of the new materials will be described in this chapter only.

6.5.1-Sensors

To implement this prototype, small appropriate sensors are needed to convert the mechanical force to electric signal which can be handled by the computer.

The following points will describe some of specification needed:

- Small enclosure that can be mounted between the rein and its grip
- Can detect any little movements
- The output signals should be modified by the regular amplifier
- The sensor has to be in low deflection which can be used repeatedly
- It has rated capacity (maximum load) up to 15 Kg
- Low cost.

6.5.2-A/D converter with amplifier

For interface the sensor analog to digital converter with amplifier is required of the prototype (III). The following points summarize the specification:

- Amplification with adjustable gain to optimize signal
- Fully embedded no control signals required can accept differential analog voltage inputs
- Analog voltage input range from 0 to 5V
- No zero-adjust required
- Has low cost.
- The digital output level should be signal 3.3/ 5V compatible

6.5.3-Processing unit

For the embedded sensing device a further processing unit was required with a similar set of requirements as for the myRIO which described in chapter four. Additional specifications are:

- Open-source, which means it is software accessible and can be use in research needs
- Can create a control program from the host PC,
- Program user can be stored and run automatically on power up

6.6-Rein prototype (III) design

6.6.1-Rein prototype (III) design block diagram

After deciding to build the prototype (III) and defining the requirements of the prototype, the electronic elements and other mechanical materials were selected:

- TE connectivity voltage compression load cell 4.5 to 45.4 kg, 5V,
- The selection of myRIO-1900,
- HX711- 24-bit analog-to-digital converter with amplifier for Weigh Scales which amplify and convert signal to digital.
- Arduino microcontroller to receiving sensors data

These components meet the specification declared previously. A schematic diagram showing the connections between these elements has been drawn, as shown in Figure (6.4).

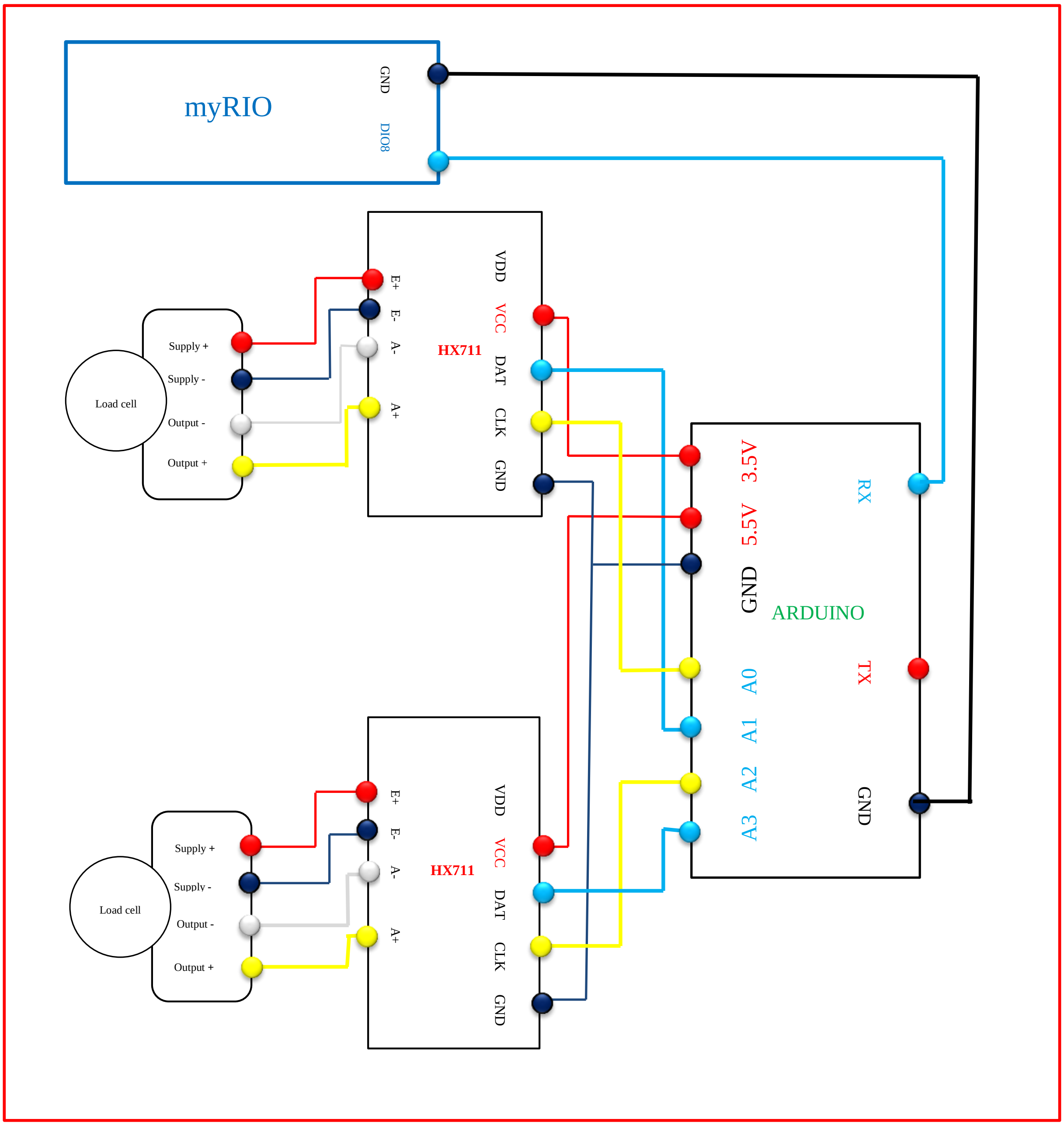


Figure (6.4) Prototype (III) tensile force sensing design block diagram

6.6.2-Prototype (III) CAD model

SolidWorks CAD model is used to determine the appropriate mechanical design as well as to help in selecting the type of material, to check the dimensions of the materials required, and experiment the virtual model which can be tested and rebuild in case of necessity. Figure (6.5) shows the prototype (III) CAD model, in this design the rein grip attached in small metal box, rein grip has pressure nail to transmit the follower tensile to load cell. as shown in the figure(6.5) when the user hold the grip and move horizontally in right or left direction the two-side pressure nail heads convey these movements to the load cell inside surface, this pressure converted by load cell (Wheatstone bridge) to low analog electric signals this signals amplified and converted to digital, furthermore sanded to microcontroller .

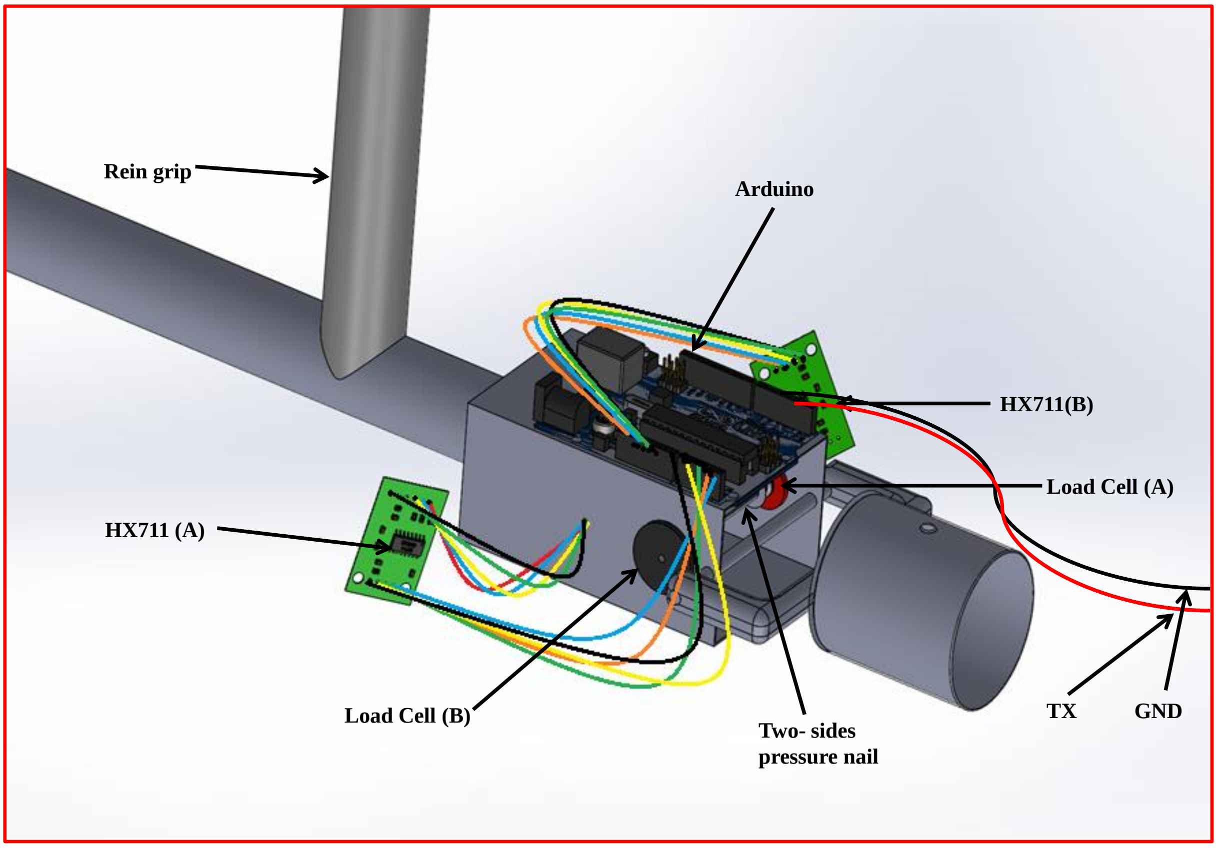


Figure (6.5) Prototype (III) control system solid work model

6.6.3-Rein prototype (III) mechanical mounting plates

After the construction and testing of the CAD model, this virtual mechanical structure is shown in the figure (6.6a) as whole structure of desired prototype body, and two-side pressure nail is used with central point to transmit the pressure of follower hand to load cell. Figure (6.6b) shows two-side pressure nail. The whole structure will attach in the upper end of rein as shown in figure (6.6c). It should be noted that two-side pressure nail is inserted inside the metal box and then it is attached by using rod in middle to be move free in the horizontal directions and its heads touch the load cells.

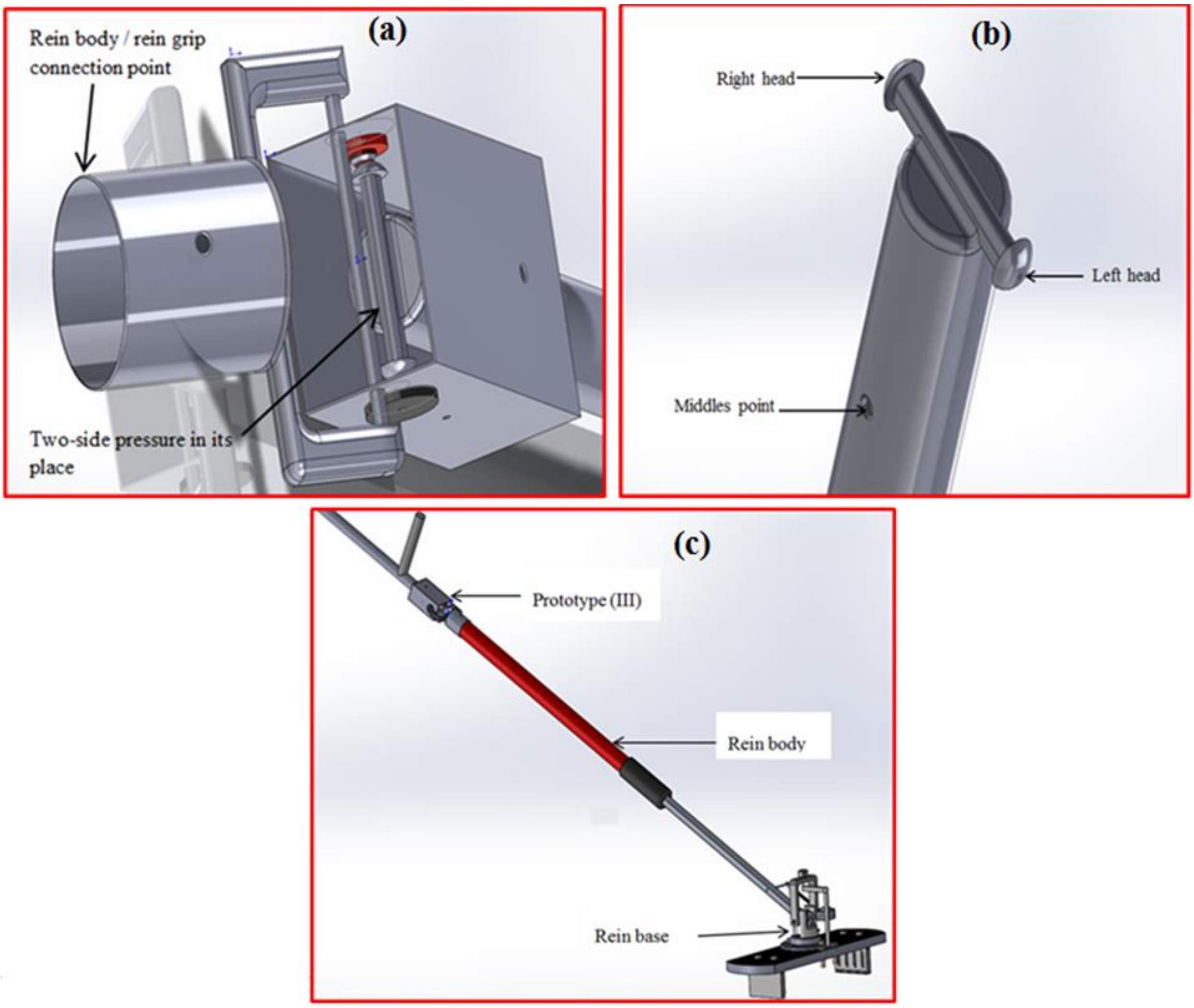


Figure (6.6 a) Prototype body metal structure, (b) Two-side pressure nail, (c) Prototype/rein connection point

6.7-Prototype (III) system implementation

In order to implement the prototype (III) tensile force sensing system, some components required. These components include load cell sensor, HX711- 24-bit analog -to-digital converter, my RIO, mechanical interface plates (load cell installation plate, two-side pressure nail, rein grip), Arduino microcontroller, and PC. The elements are connected with each other to achieve specific goal, which is gathering and processing data coming from load cell to measure and monitor the value of tensile strength occurs between the follower hand (rein grip) and the rein.

6.7.1-Load cells / pressure nail / metal plate's connection

In order to make the mechanical structure work well, it was first necessary to install the load cells in the specified locations. Then the two-side pressure nail (shows in figure 6.6b) is installed exactly in the middle point between load cells, it moves freely on the horizontal plane allowing the nail/pin to contact the faces of load cells when force is applied. In that case any movement on the two-side pressure nail will act directly in the load cells as shown in figure (6.6a), and the load cell will convert these movements to analog electric signal.

6.7.2-Connect load cell with A/D converter

After selecting the appropriate load cell in terms of rated capacity, rated output and recommended excitation voltage as well as selecting the HX711 that provides the appropriate gain to amplify the small analog signals that produced from load cells, both load cells are connected to the HX711. The function of this HX711 is to amplify and digitize the low analog signal coming from the load cells. Where supply + (VCC) in the load cell which have red color connect with the E+: *Excitation positive* of the HX711 and supply- (GND) in the load cell connected to E-: *Exaltation negative* in the HX711 which has black color and output**-** is connect to A-: *channel A Negative input* which has white color in block design also, output+ in load cell Connected to A+: *channel A positive* input has yellow color. Block diagram figure (6.4) shows all these connections.

6.7.3-Connecting A/D converter to Arduino

As shown in the design block diagram figure(6.4), there are some connections that belong to the both HX711 and Arduino, the first is ,HX711 and Arduino microcontrollers connection, where VCC in both HX711 is connected to 5.5,3.5 V in Arduino and GND in both HX711 is connected to GND in Arduino and DT: data I/O for HX711 (A) is connected to channel A1 in Arduino which has blue colour in figure(6.1) and DT: data I/O for HX711 (B) is connected to channel A3 in Arduino which has blue colour, also SCK :serial clock input which has yellow colour in both connected to A0for HX711 (A)and A2 for HX711 (B) as shown in figure (6.4).

6.7.4-Arduino/my RIO Connection

To send the received data from the load cell to myRIO, it was necessary to connect the RX of Arduino to one of the myRIO channels as shown in the figure (6.4) after selecting the baud rate for both. In this case the system hardware installation was finished and the test was ready after running the LabVIEW program.

6.7.5-Lab VIEW program

In this prototype a lab view program has been created to receive data from the Arduino, gathering and sending these data for processing and use. Moreover, it is necessary to write Arduino programs for receiving the data from the load cells and send it to myRIO, (Appendix D) shows lab VIEW program for this prototype

6.8-Prototype (III) system test

6.8.1-Starting prototype (III) system test

To start the system prototype, some points should be observed such as ;(i) system hardware components were connected to metal plate, (ii) load cells were connected to the HX711, (iii) both HX711connec to Arduino, (iv)Arduino RX connected to my RIO -DIO8, (iiv) the my RIO is connected to power and PC host computer by USB. The data will flow from load cell to PC via Arduino and myRIO. Lab VIEW program should be running to identify the myRIO and receive, process and monitoring data for use in tensile strength measuring. Figure (6.7) shows prototype (III) real system structure.

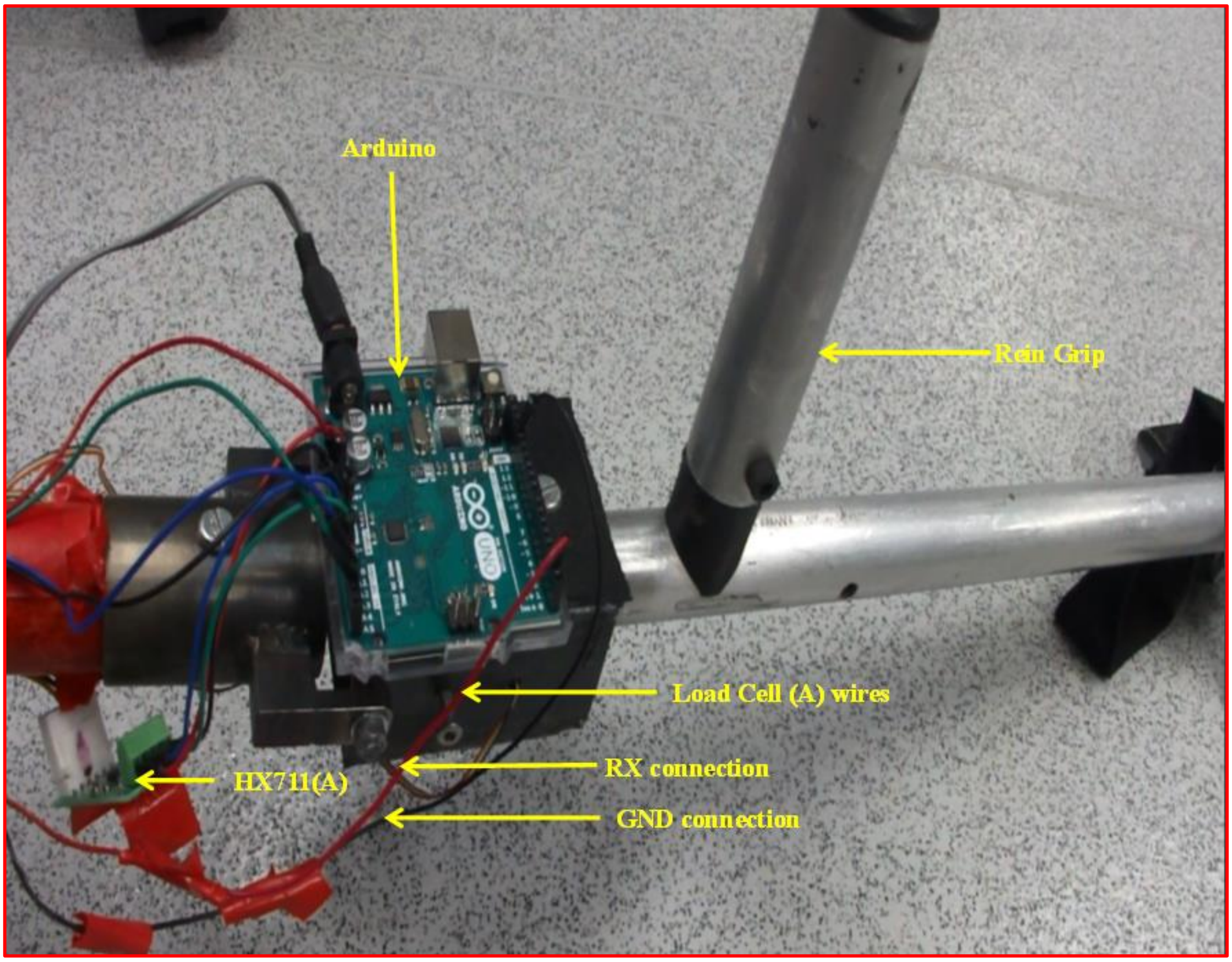


Figure (6.7) Real system structure

6.8.1.1-TE load cell calibration

In this research the load cells were calibrated to change values of voltage to equivalent tensile strength by Nm by using LabVIEW program and a force meter, all converted readings were recorded and stored. The figure (6.8) shows how the calibration was done.

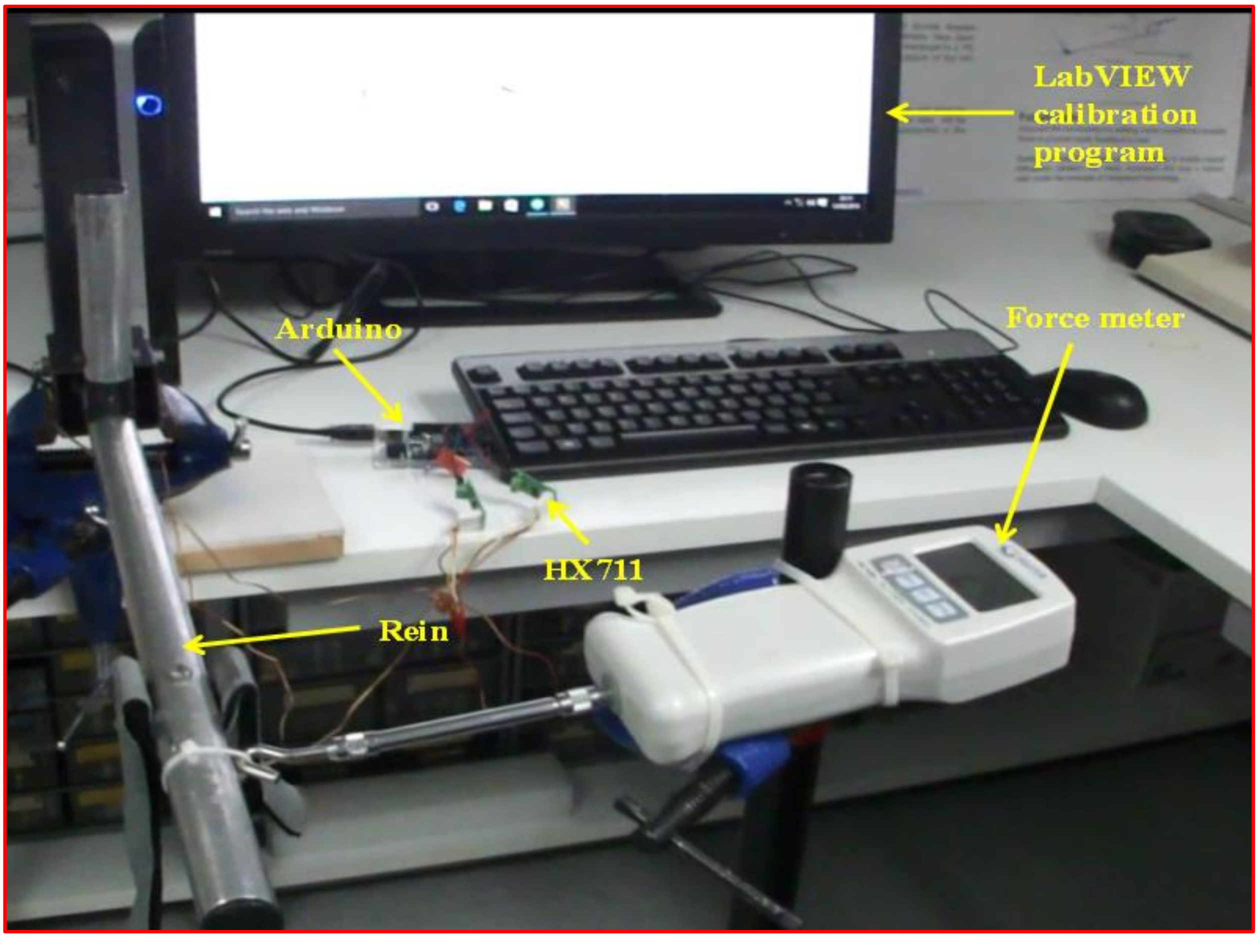


Figure (6.8) Load cell calibration

6.8.1.2-System calibrating procedure

1- Install the system and connect it to the PC

2 - Running LabVIEW program for reading sensors

3 - Perform a small test to make sure that the LabVIEW program and sensors work properly

3- Joint rein grip to the Force meter

5- Move the Force Meter until it registers reading 1 Newton

6- Change the value of offset until LabVIEW indicator shows 1

7- Repeat this for the both sides on the two indicators (left/right indicator) with many values of force to make sure the system is calibrated well

8- Do final check by moving force meter and notes the indicators readings

6.8.2-Prototype (III) system test procedure

The test of this prototype can be seen in chapter 3 section 3.2(Preliminary system test)

6.9-Conclusion

The test on the prototype (III) explains that the system can be used to detect the tensile strength that occurs between the forearms of the follower and rein. With this consideration prototype (III) is suitable to detect the follower hand/rein tensile force which occurs between the rein grip and rein axis as result of follower hand and rein tensile strength. Based on the sensor data the control signals have been then be sent to move the rein for reducing the tensile force in order to increase the follower comfort and maximize the ability for the follower to accurately follow the robot path.

Chapter Seven

PROTOTYPE FOUR (SHARED CONTROL SYSTEM)

7.1 Introduction

In order to achieve mutual understanding between the follower and the robot and make the follower's path close as possible to the robot path, the whole system was divided into several prototypes. The prototypes will be integrated into a single comprehensive prototype (IV), works to identify the follower's location and move it very smooth to be close to the robot path. The final prototype which will be used in this chapter combines from the previous subsystems to create the shared intelligent control system. The shared control relationship is complex as it has to meet the requirements of two independent systems (the follower and the robot) with different behaviour (Wang and Liu, 2014). This prototype needs to establish suitable shared control and provide a level intelligence by emulating the natural relationship observed between a guide dog and the human follower. In plain terms it has to to reduce the deviation between the follower and robot paths and provide a high level of comfort, Figure (7.1) shows the deviation in paths with the robot path in blue colour and the follower path in yellow.

To create the physical system, all prototypes are integrated and mounted on the surface of the mobile robot along with additional batteries and voltage regulator circuitry to provide power for Arduino, myRIO and motor. Moreover, the myRIO was converted to the router and connected to a PC wire Less for all the data transmission, a Lab VIEW program was also developed to remotely send commands and receive data through the system.

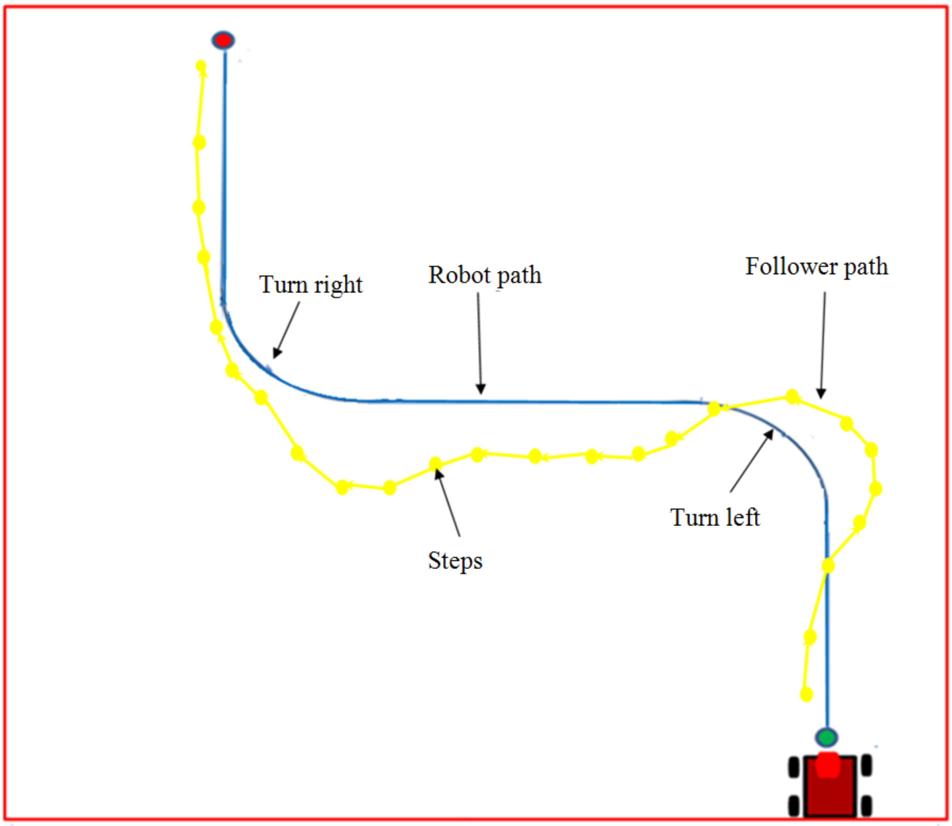


Figure (7.1) Deviation in paths

7.2-Prototype (IV) problem definition

To reduce the deviation between the robot's and the follower's paths and optimize the follower levels of comfort, it was necessary to develop a control system which supports these criteria. This system should provide a mutual language between follower and robot by sending haptic control signals from the follower to the robot and feedback signals from the robot to follower through the hard rein.

In practical terms the problem of this prototype is how to make the rein move in the horizontal direction taking into consideration the follower's position by accepting the signals coming from the load cell.

7.3-Rein prototype (IV) aims

This prototype aims to integrate all of the previous prototypes and attach them to the hard rein. The complete system will be placed on a mobile robot; this system has the ability to send and receive data. Moreover, a LabVIEW program must be developed and applied to sending control instructions.

7.4-Shared Control Strategy

The Intelligent hard rein has been modified to include the following items: sensors to detect the follower's location and measure tensile forces occurring between the follower's hand and the rein. The PC gathers the sensor data and generates appropriate control signals to control the movements of the motor which moves the rein and guiding the follower.

7.4.1-Follower -robot Shared Control

Our goal is to allow the follower to follow the robot path accurately as possible in the navigation process. Eventually the system may be useful for firefighter in rescue operation.

At first, the system collects information from the sensors about the position of the follower. Then, the information is analysed to determine whether the robot in rotation and the follower can’t follow the robot path, in this case the rein moves to allow the follower to follow the robot, these movements are implemented based on sensor data, and by using sensor output. The system can distinguish between several force levels. (*In the system use some contingency ranges of angles which allow rein to move and don't go out of range for example [205-193] & [145-147] & [110-113]*):

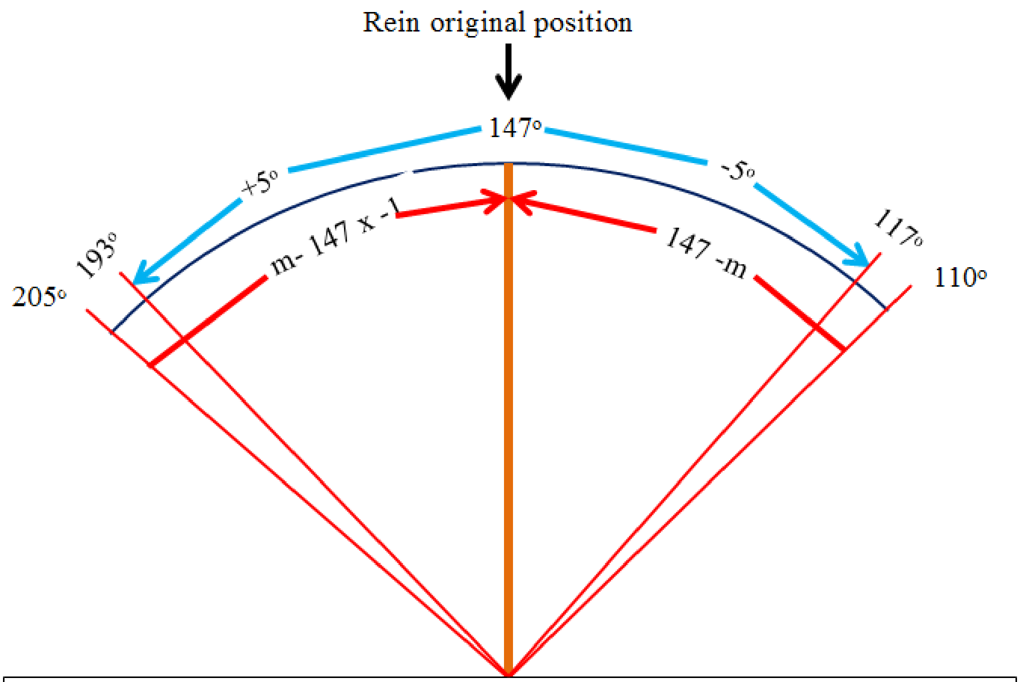
Low tensile force level (A): The range of tensile force of both sensors, greater than 0 and less than or equal 0.3 Nm, in this range the rein does not move to allow follower to do little movements without movement of rein.

Medium tensile force level (B): When the range of tensile force sensor S1 is between 0.3Nm and 2Nm, and motor encoder (m) reading between110°-147°, in that case the rein will move by value of (147°- motor encoder value), this movement toward the follower hand to minimize the tensile strength, if not the rein will not move.

And if the tensile force of sensor S2 is less than or equal 2Nm and greater than 0.3Nm, and motor encoder reading less than 205° and greater than or equal 145°, in this case the rein will move by value of (motor encoder -145° x - 1), if not the rein will not move.

High tensile force level (B): If the tensile force of sensor S1 is greater than 2 Nm and less than or equal to 10 Nm, and the motor encoder reading is less than or equal 193° and greater than or equal to 117° in this case the rein will move by value of -5°, this movement toward the follower hand to minimize the tensile strength, if not the rein will not move.

If the tensile force sensor S2 is greater than 2 Nm and less than or equal to 10 Nm , and reading motor encoder less than or equal 193° and greater than or equal 117° ,in this case the rein will move by value of +5°, if not the rein will not move, figure (7.2) shows rein movement's path where the rein movements ±5 is coloured by blue and turn back by red



m = Rein (follower) current position, and directions are reversed because the of flexible rope motor rein base connection , In the system use ranges of angle [205 -193]& [145-147]&[110-117] to guarantee the rein return in the end

Figure (7.2) Rein movement's path

Based on the tensile strength force happen between the follower and rein can conclude:

1. Range of tensile force is located from 0 to 0.3 Nm permits the follower to do little movements before he/she start the walking (for example when the follower attached the rein and the robot doesn’t move in that case he/she can do a little movement without causing motor movements)

2- Range located over 0.3 to 2 Nm; the rein provides rotation against the follower hand using the tensile force strength level to make follower follow and turn the rein in the straight with the robot body axis

3- Range of tensile force is located from 2 to10 Nm the rein provides continues movements by ±5° dependent on follower location, to increase the follower comfortability and make him follow the path

4- Maximum range of rein angle movements are from 110° to 205°

In this control strategy the movements of rein depend on the follower location as first factor and the tensile force exists between his hand and rein, as second factor, these factors have strong relation with the robot movement.

7.5-Shared control flow chart

Flow chart diagram of shared control system shown in figure (7.3) where S1 indicates the left sensor and S2 indicates the right sensor and m indicates the position of follower and z the motor direction input (*In the system use some contingency ranges of angles which allow rein to move and doesn't go out of range for example [205 -193]& [145-147]&[110-117]*) .

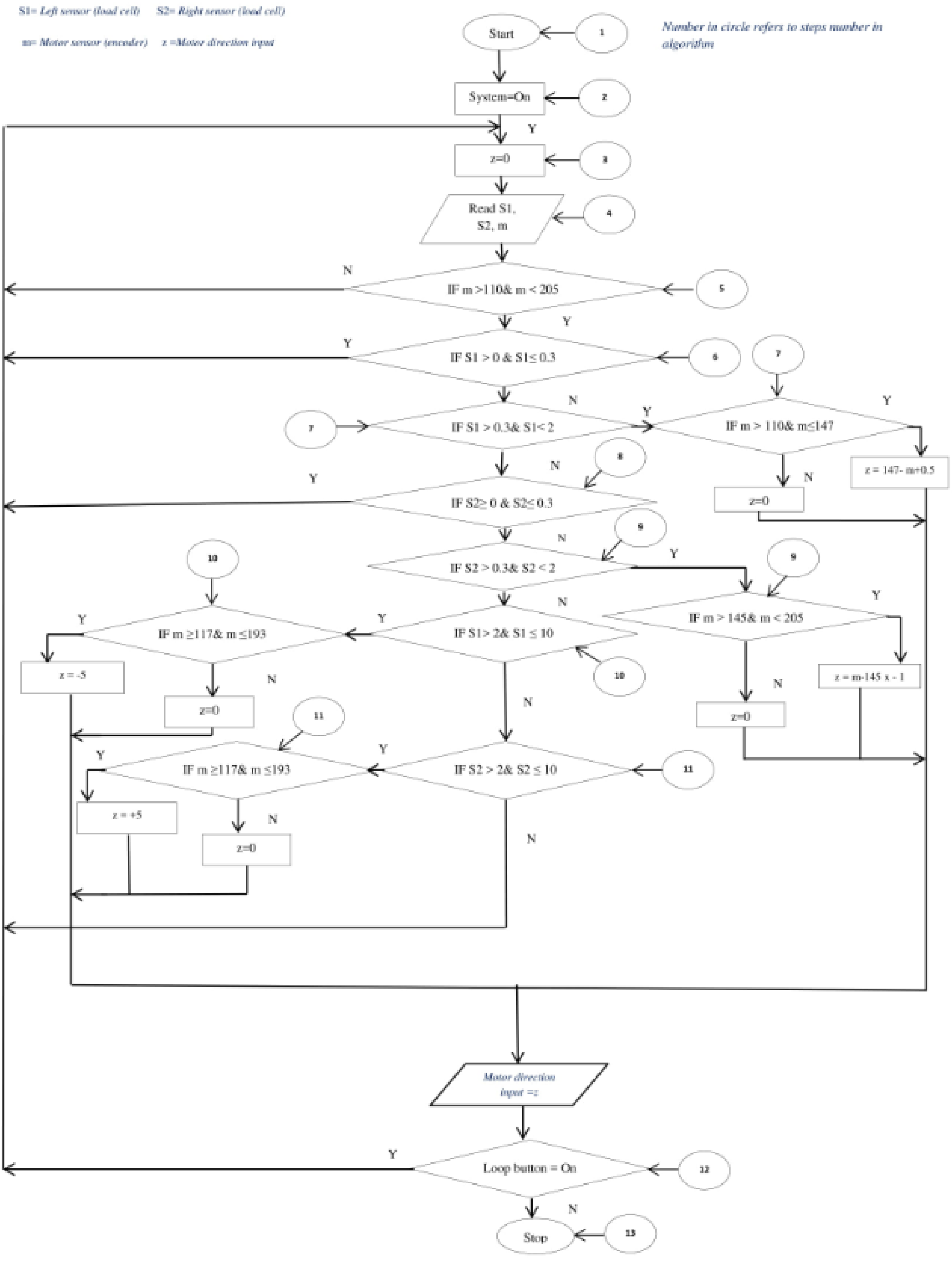


Figure (7.3) Shared Control flow chart

7.6-Shared control algorithm

The problem is: how to make the stepper motor move the rein in the horizontal direction with the consideration of follower position and make him smoothly follow the robot , and steps of this algorithm are :

Step 1: Start

Step 2: If system power ON

Step 3: Initiate motor direction by putting 0 in it is direction register z, (z=0).

Step 4: Read S1: tensile force value of left load cell, S2: tensile force value of right load cell and m: value of motor encoder

Step 5: Specify the whole system scan limitation (the whole range of angles where the follower position can be detected /defined) and this range starts at 110° and ends at 205° where the mid is 147° , as shown in figure (7.2). If (follower position) in this range true, go to next step, if false go back to motor register initialization step (step No 3)

Step 6: If the S1 greater than 0Nm and less than or equal 0.3Nm true, in this case the rein will not move (allow the follower to do little movements without any system action) and go back to initialization motor register (step No 3), if false go to next step.

Step 7: If S1 greater than 0.3Nm and less than 2Nm false go to next step, if true do check about the follower position if follower position greater than 110° and less than or equal 147° true, then the value of ((147- current follower position) +0.5°) will put in motor direction register z, if not 0° will put in motor direction register z.

Step 8: If the S2 is greater than 0Nm and less than or equal 0.3Nm true, in this case the rein will not move (allow the follower to do little movements without any system action) and go back to initialization motor register (step No 3), if false go to next step.

Step 9: If S2 greater than 0.3Nm and less than 2Nm false go to the next step if true do check about the follower position, if follower position greater than 145° and less than 205° then the value of ((current follower position - 145) x -1) will put in motor direction register z, if not 0° will put in motor direction register z.

Step 10: If S1 greater than 2Nm and less than or equal 10 Nm false go to the next step if true do check about the follower position if follower position greater than or equal 117° and less than or equal 193°, in this case put -5 to the motor direction register, if not put 0 in motor direction register z.

Step 11: If S2 greater than 2Nm and less than or equal 10 Nm false go to the initialization motor register (step No 3), if true check the follower position if follower position greater than or equal 117° and less than or equal 193°, in this case put +5 to the motor direction register if not put 0 in motor direction register z.

Step 12: If loop button ON, go to the initialization motor register (step No 3) if not go to stop.

Step 13: stop

7.7-Rein prototype (IV) system building specification

This prototype is a combination of all previous prototypes and requires all the sub systems to be integrated together in one complete system and put on the limited robot surface.

7.7.1- Lithium batteries

- Voltage 12.8 or 24V connected to system power supply
- Has high efficiency
- Small in size because of robot area.
- Can be recycled for environmental protection

7.7.2- DC/DC Rectifier

- Has high input range 36V and output is 10V for microcontroller and myRIO
- Output 0 to 24 V to use for microcontroller and other equipment which need 10 V
- Startup production for misused
- Low price to appropriate for research limited budget

7.7.3-PCB board

To use in prototypes, microcontroller, motor and encoders connections

7.8-Rein prototype (IV) design

7.8.1-Rein prototype (IV) design block diagram

After deciding to build the prototype (IV) shared control system and determines the purpose of this prototype, a block diagram has been drawn show the connection between all prototypes as shown in figure (7.4).

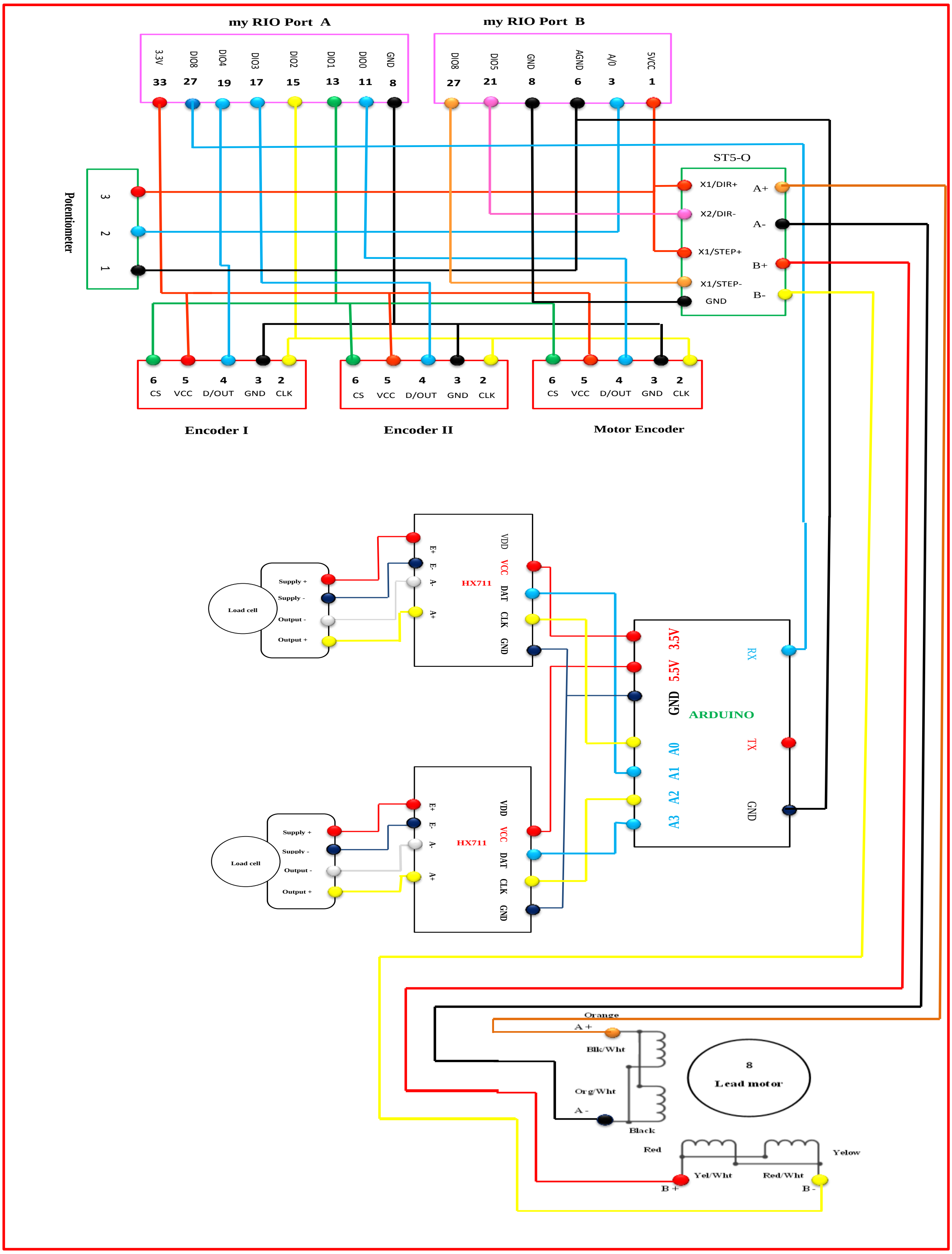


Figure (7.4) Prototype (IV) shared control system design block diagram

7.8.2-Prototype (IV) CAD model

The CAD Solid Works model was created to help with the physical design and optimize positioning and assembly of all the prototypes. Figure (7.5 a, b) illustrates the main structure of prototype (IV) and whole view of the final system and figure (7.6) shows the arrangement of how the motor is attached to rein via a flexible metal rope. After significant testing of the model, we can know the best construction of the system.

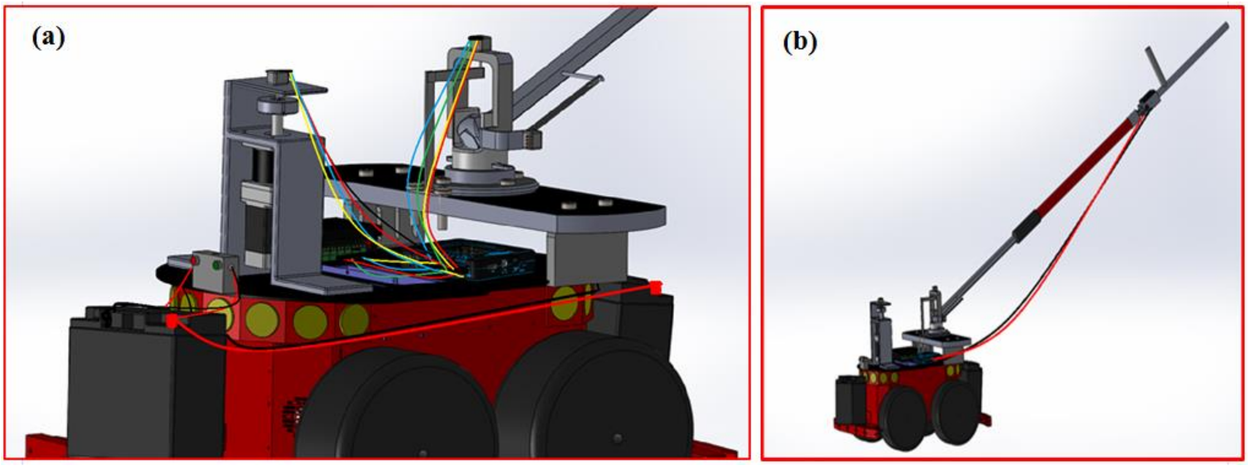


Figure (7.5 a) Prototype (IV) shared control system assembling CAD model, (b) Assembling of the whole system

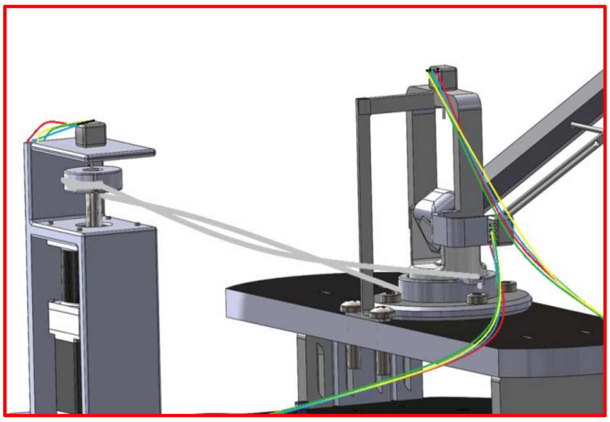


Figure (7.6) Motor/rein attachment

7.8.3-Rein prototype (IV) PCB mounting board

When constructing the system the large number of physical connections and complexity of the wiring made the system unreliable and difficult to fault find. A bespoke PBC was therefore designed to minimize the number and variety of connectors the PCB board photo is shown in the figure (7.7a), and its scheme in figure (7.7b).

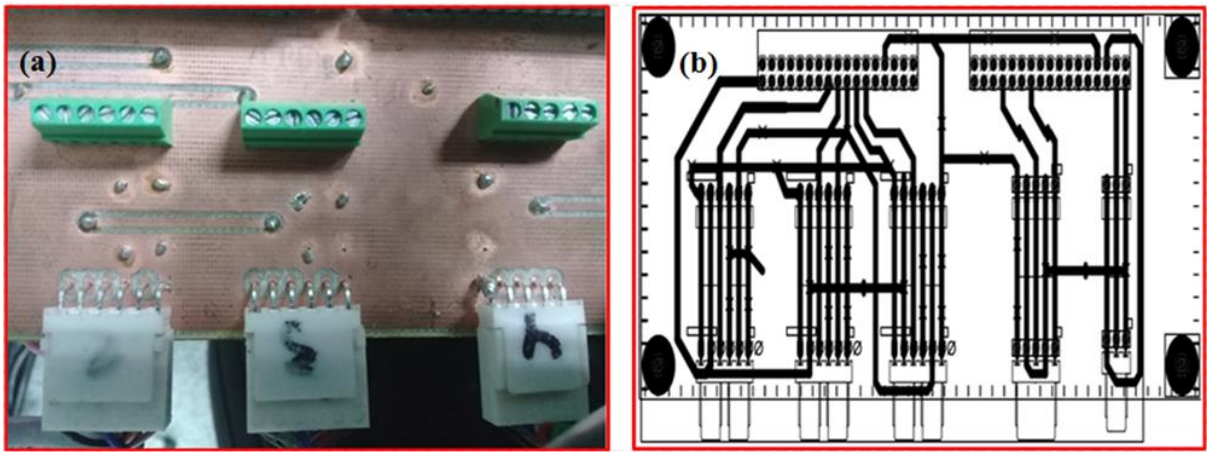


Figure (7.7 a) PCB board, (b) PCB board scheme

7.9-Prototype (IV) implementation

After the block diagram of system connections had been drawn and the CAD model used for checking the assembly location placement, orientation and issues with movement/obstruction, the prototype (IV) was straight forwardly manufactured. Prototype (IV) needed some extra components especially which related to power supply. These components including rectifier with output 3.3 to 24 voltage dc (mt-system, 2016), three batteries of 12V-9Ah, switch for the electric circuit control, shielded electric wires, PCB board, and Pioneer 3-AT mobile robot platform. The implementation follows the following steps:

- The prototype (II), which composed from stepper motor and encoder as described in chapter five, will be installed on the front of the robot surface and will be firmly fixed.

- The encoders with metal plate mentioned in prototype (I) and explained in Chapter 4 will be jointed to the hard rein base.
- The rein placed on the back of the robot as shown in figure (7.5a) by use suitable screws.
- The prototype (III), which has two of load cells connected with Arduino, installed at the end of the hard rein (where the follower holds the rein grip) to calculate the tensile strength of the follower's hand.
- The stepper motor will be connected to the ST5-Q diver as explained in chapter 5 as well as the driver connected to myRIO via PCB board.
- The motor encoder which explained in chapter 5 and the rein encoders which explained in chapter 4 will be connected to myRIO via PCB board.
- The components of the prototype (III), which used to measure tensile force, will be connected to each other. The load cells will connect to HX117 amplifier and A/D converter the output of the amplifier will connect to Arduino, as mentioned in chapter six, and after that, the Arduino connected to my RIO on two lines RX, GND.
- Three 12-volt batteries will be connected in series circuit with the switch-off key, to get 36-volt as a power supply for the system.
- The output voltage of the batteries connects to the rectifier to get10V as a power supply for Arduino and my RIO.
- Changing my RIO as an access point to connect with Wi-Fi in order to receive the system data.

- In order to collect load cells data which connected in the prototype (III), a program is required to run for receiving the sensor data and send it to PC via myRIO for processing.

- On the other side, connecting the PC computer with my RIO via an access point and the whole system LabVIEW program was developed, this program will run to test and operate the whole system.

7.10-Prototype (IV) test

7.10.1-Initiate the test

To test the prototype (IV) shared control system, it is necessary to make sure that all prototypes were physically fixed and connected to the data acquisition system (my RIO). Furthermore, my RIO is connected to power and PC host computer by USB. The data will be transferred from all prototypes to a PC via myRIO. Figure (7.8) shows an image of the whole system structure.

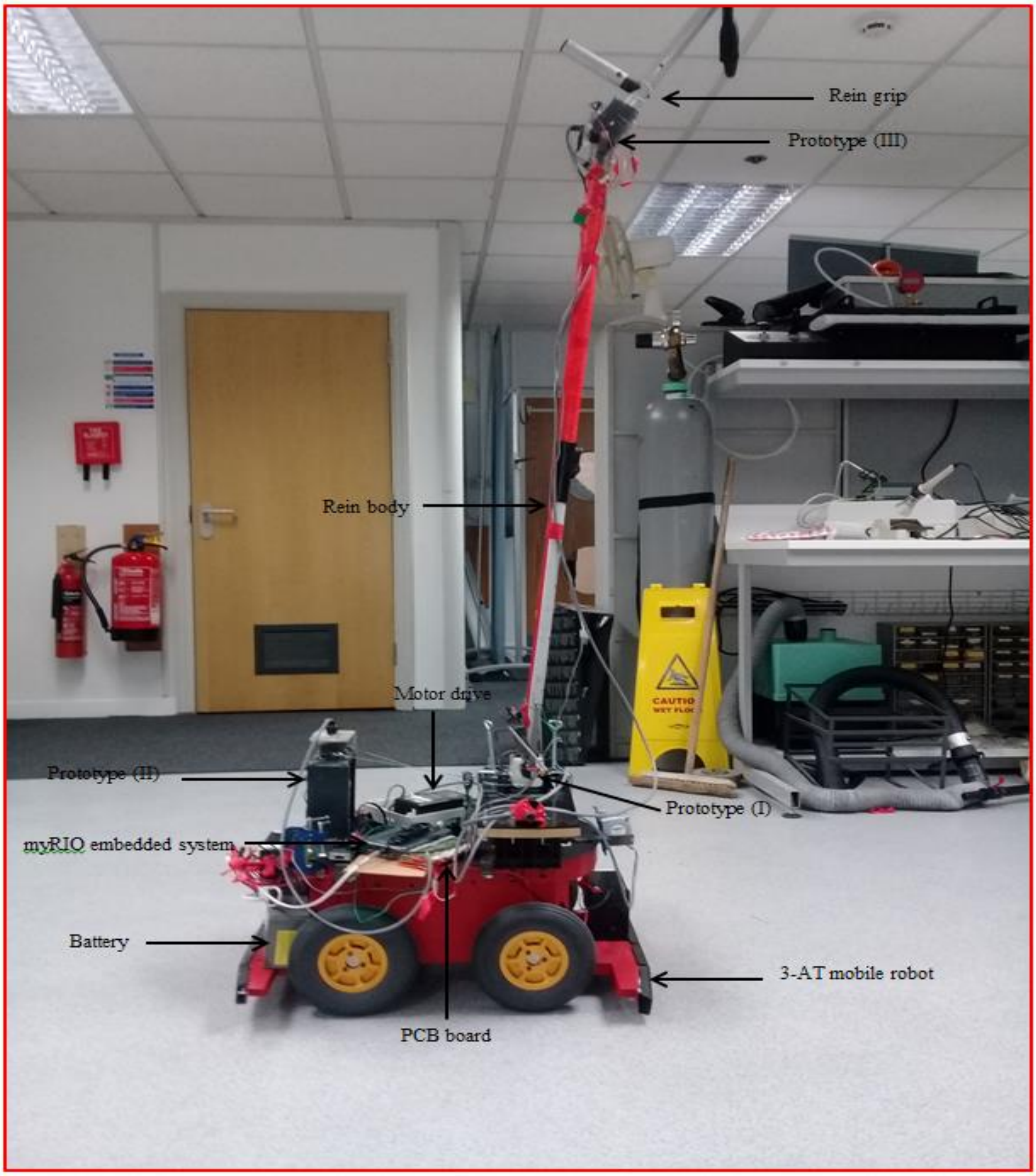


Figure (7.8) Real whole system structure.

7.10.2-System test path

The desired path of the robot was measured and drawn on the ground, this was made to match the same path used in previous tests with different robot speeds, in order to make easy comparison between their results as shown in figure (7.9).

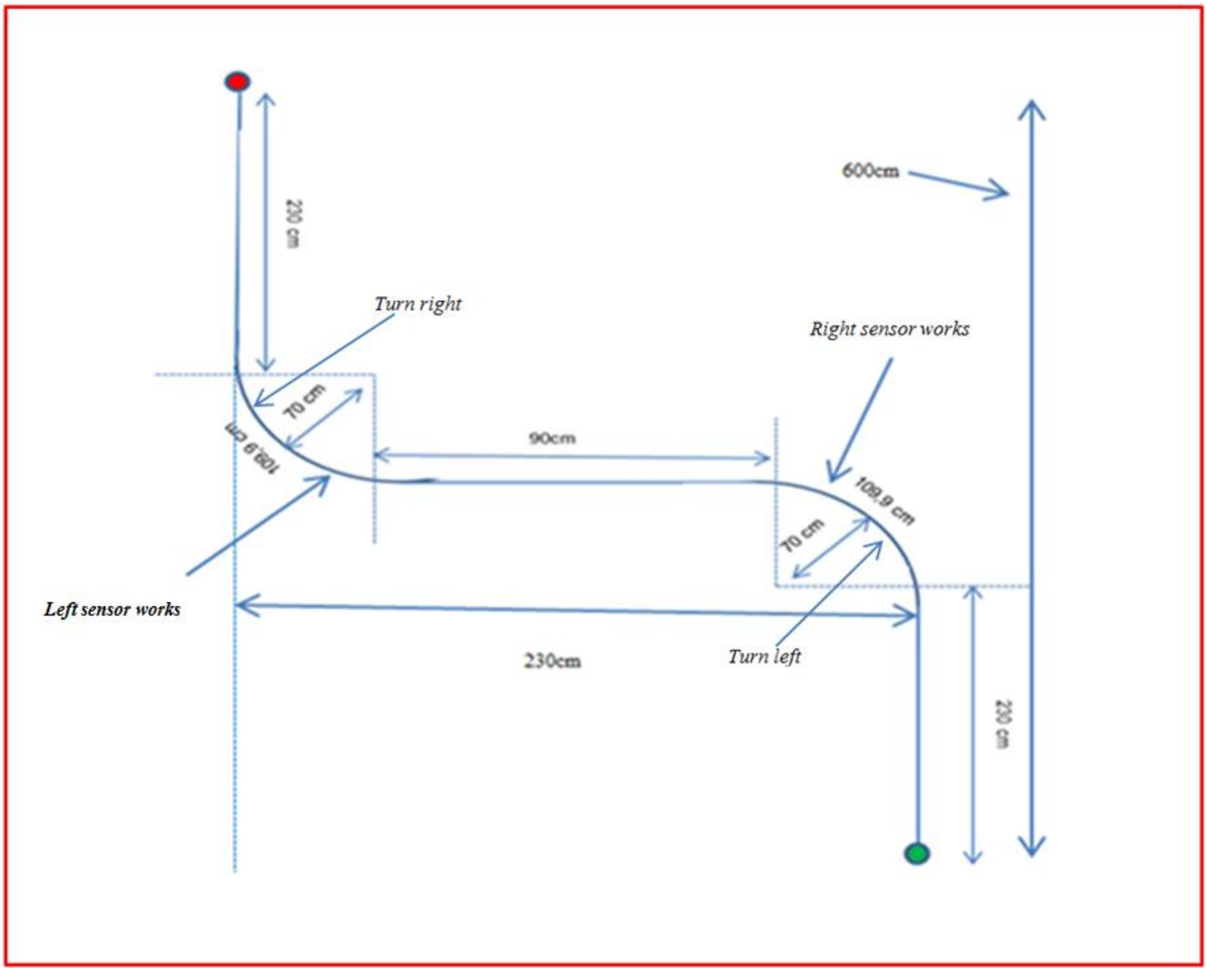


Figure (7.9) Test path

The total distance moved by the robot is 769.8 cm and the speed of the robot is 20.1 cm/s (robot speed is different from the preliminary test speed), so the time to move the total distance is 38.29 seconds, with these facts the test has been done.

7.10.3-Prototype (IV) test methodology

The preliminary test that has been described in chapter 3 explained the full procedure which was used when undertaking these tests. Figure (7.10) illustrates the participants attached to the rein with the wrist strap which joint to the rein and the participant is blindfolded. Subsequently, the robot movement was started with no external prompt. It moved forward to 230 cm, then rotates to left side on a circular by a distance of 109.9 cm and continued to move forward by a distance of 90 cm. After that, circular rotation was used to turn to the right side with a distance of 109.9 cm. The final section of the path continued forward 230 cm and stopped completing the entire journey.

Figure (7.10) Participant follows the Robot

When the robot and follower have completed the path the blindfold was removed, the researcher presented the survey from to be filled in by the participants. The data collected from the survey is put into the table to be analyzed, table (7.1) shows the collected data.

Comfort level	1	2	3	4	5
Forward	0	0	1/5	3/5	1/5
Turn left	0	0	2/5	2/5	1/5
Turn right	0	1/5	0	3/5	1/5

Table (7.1) Test subjected data in forward, Turn left and Turn right

7.10.4-Prototype (IV) subjected test data analysis

From the analysis of the previous table, it's clear that the participants are very comfortable when the robot is moving forward and turn left because most of the participants have chosen the third, fourth and fifth level on the comfortability index. Also turning right has acceptable amount of comfort. In this test, it is clear that the comfort feeling is acceptibale because major of the participants (83%) choose levels 3, 4, 5 which located after 2.5 in the index level, where the rang (2.5 to 5) can be considered as acceptable comfort feeling, where 5 is the maximum and 2.5 is minimum, as shown in the following figures (7.11), (7. 12), (7.13).

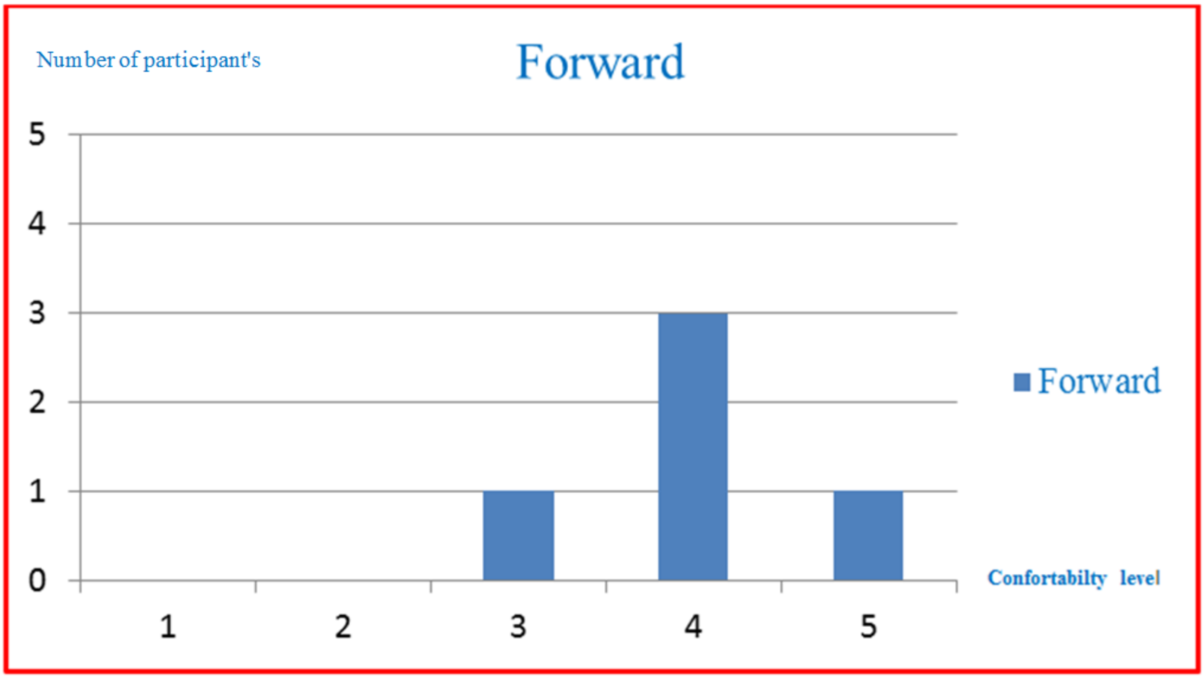


Figure (7.11) Participant /comfortability level (Forward)

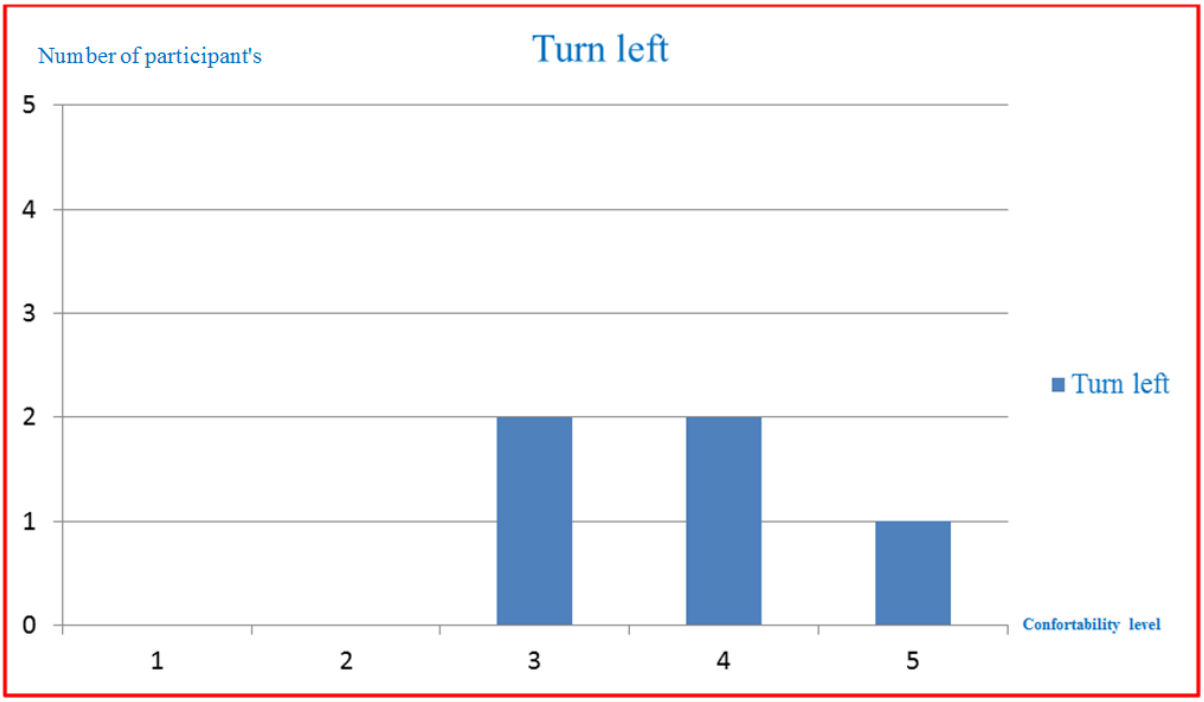


Figure (7. 12) participant /comfortability level (Turn left)

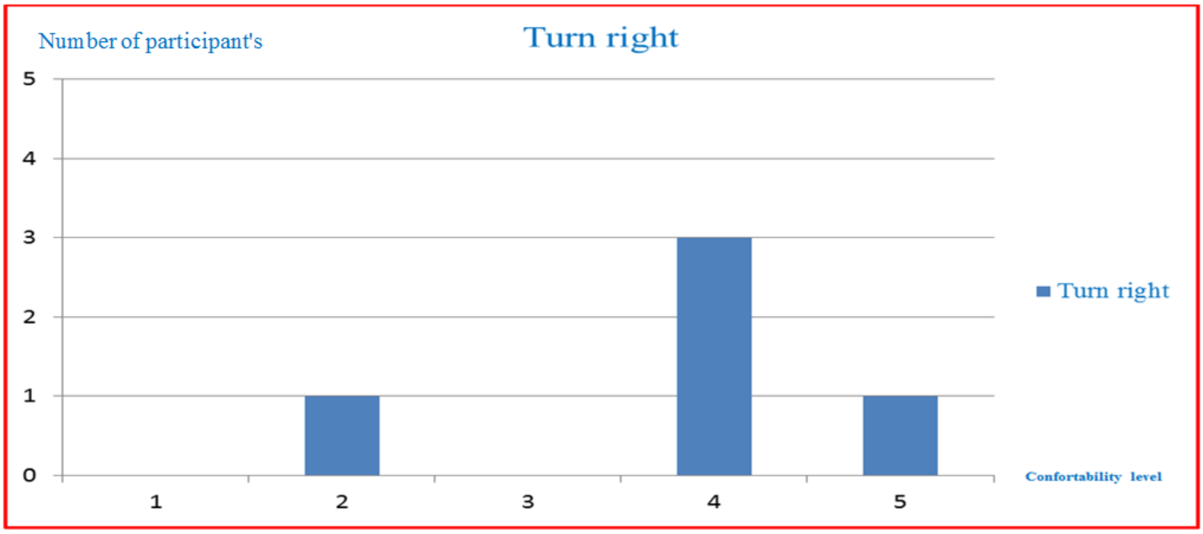


Figure (7.13) Participant /comfortability level (Turn right)

7.10.4.1-Objective data collection& analysis

The objective data obtained from the sensor readings are collected and plotting, the following table (7.2) demonstrate highest and lowest rate for the left and right sensors and in which readings order were happened, the word reading in next table means in which order the data was taken from the sensor, appendix (G) shows samples (participants) data reading details (The sample data mean the data collected from the sensor during one participant trial):

Sample (participant order)	1		2		3		4		5	
Right / Left (Sensor)	LS	RS	LS	RS	LS	RS	LS	RS	LS	RS
Highest rate	4	4	5	6	4	6	6	6	6	6
Data reading order	32	14	44	32	35	22	33	35	35	22
Lowest rate	0	0	0	0	0	0	0	0	0	0
Data reading order	36	19	48	36	38	25	51	37	38	25

Table (7.2) Highest and lowest rate

In the table (7.2) when put the 0 reading number mean the lowest level after the sensor has get it maximum force level and also the highest reading mean when the sensor reach the high level and this level repeated more than 3 times (in table write one of these readings number), the following is the description of the first sample(paricpant). In the first sample, the highest reading achieved by the right-sensor is 4Nm at reading order 14 ,15,16,17and the lowest rate is 0Nm at reading order 3 to 5,8 to 14,20 to 44 ,46 to 50,55 to68, and the left-sensor has achieved the highest rate of 4Nm at reading order 33,34,35 and the lowest reading is 0Nm at reading order 4 to22 ,25 to 32, 36 to50 , 54 to 66. Figure (7.14) shows dataset of the first sample during one cycle of the path as an example where turn right by blue color and turn left by brouwn color.

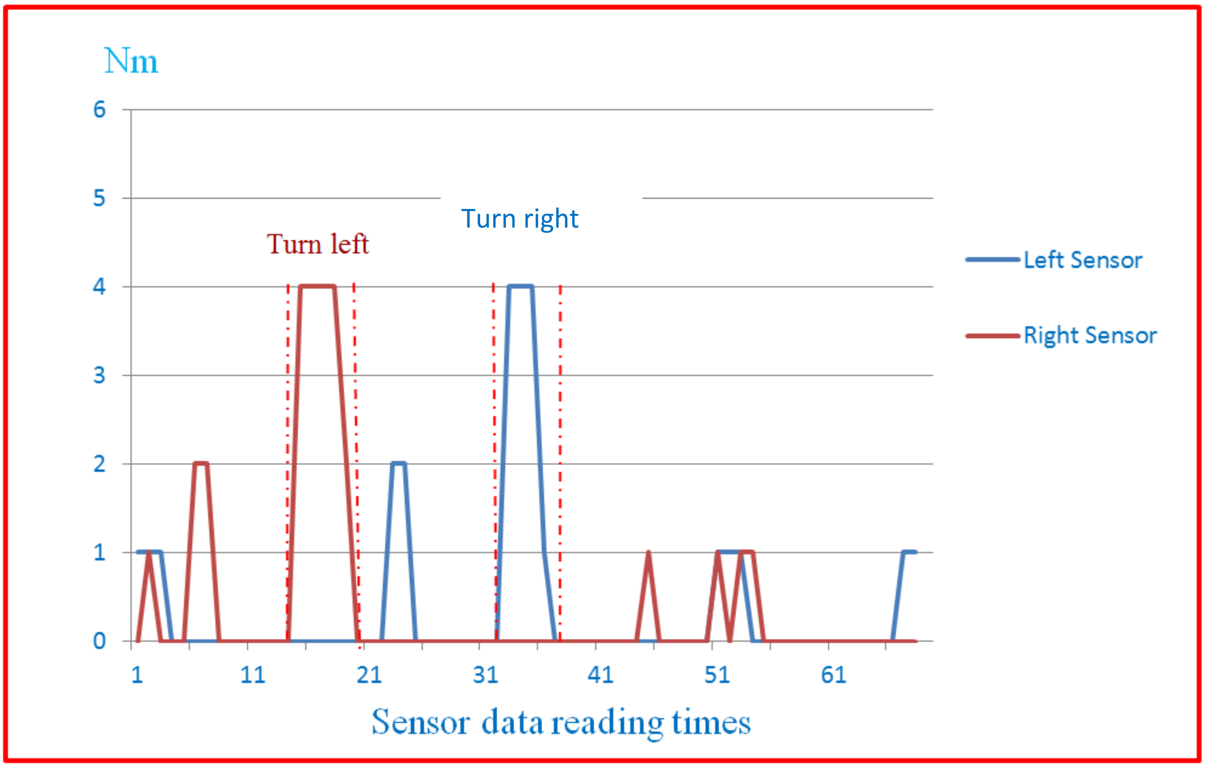


Figure (7.14) Example of dataset during one cycle of the path.

7.10.4.2-Prototype (IV) test follower cumulative steps analysis

After the test is finished, a follower path was reviewed and tracked by plotting a location of user steps to create the path and comparing this path with the robot path The deviation between the follower and robot in the rotation can be noted, determined and used as a reference to know the follower can follow the robot path smoothly or with difficulty. From the results of this test, it is clear that the deviation decreases in the turn left and right except a little difference because the follower handles the rein with the right hand and his body away from robot centre axis by 20 to 25 cm. So, we can note this little deviation starts from beginning of journey and can be neglected, figure (7.15) shows deviation in paths, where the robot path by blue colour and follower by yellow.

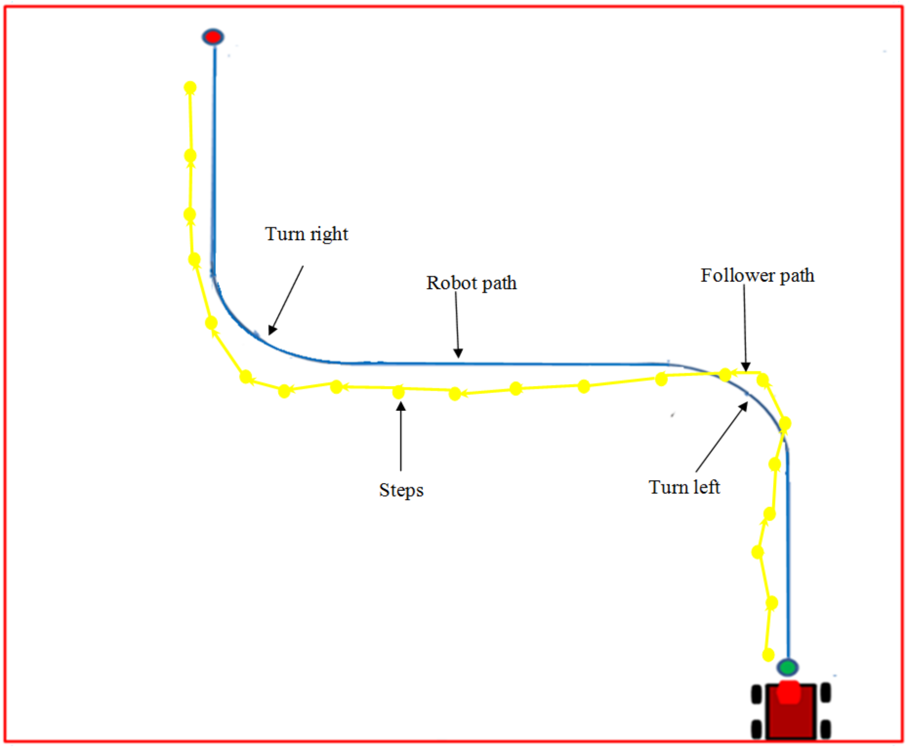


Figure (7.15) Deviation in paths

7.10.5-Prototype (IV) system test conclusion

1- After the data is collected and analyzed, the survey data shows that the straight path is the most comfortable for the participants and the turn left/right is ranked next in comfortability feeling, and in general this test more comfortable for participants because all samples choose the comfortable levels located after 2.5 level indexes.

2- The participants do some stagger during the following of robot in the side of the right sensor and it is clear from some registered readings this happen in the beginning of the movement and before and after the completion of the rotation as shown in figure (7.14).

3- Through the analysis of objective data, there are readings of the sensors in both directions which indicate the participants stagger or are jolted by the movement. This was seen visually during the experiments and also it was explained by the measured force data between the follower and the rein. The resistance/force between the follower's arm and the rein is different and reaching up to maximum 6Nm in some samples when turn left and 3 Nm in some samples when turn right , but it has been noted that the force level remains for a longer period in the right sensor(turn left) than the left sensor(turn right) , as shown in the figure (7.14).

4- Through the previous analysis, the tensile strength doesn't exceed the 6Nm in all samples, because the motor moves the rein toward of follower's hand to reduce this force.

5- Analysis of test images clearly show a little deviation between the real (robot path) and follower path, this was because of the potential difference between the robot centre axis and follower hand the (the rein fixed robot in the middle axis).

7- The system structure is not reliable and some damages happen during the test.

8- The test shows there is a possibility of robot slip.

9- Can say this shared system has achieved aims of research, but still need a lot of work to be reliable.

7.11-Conclusion

It is clear from this chapter; the full movement rein has the ability to takes a step forward from previous designs in attempting to achieve the human-guide dog relationship. For that it is an acceptable method to deliver haptic feedback from the robot to the follower. The system can be considered as a good starting point in the knowledge of how to use and transfer a haptic signal between human and the robot. Also, it is considered a successful and reliable participatory system in future research, although some mechanical design issues are evident, the robustness and precision of the construction could be improved with better materials. However, the objectives of the research have partially been achieved in making the follower follow the path of the robot and also create simple communication between the follower and the robot using the haptic signals.

Chapter eight

DISCUSSION AND CONCLUSION

8.1-Introduction

The essential points of my research will be reviewed in this chapter. The improvements of the system and the major findings will also be discussed. Then, a conclusion and recommendations for future research will be presented.

8.2-Discussion

In this discussion, we will evaluate the system before and after the development and see how much improvement it has made in terms of: a) improved the follower path- how accurately the follower tracks the robot path b) decrease of the fluctuation (follower Staggering) which may cause unconformable feeling.

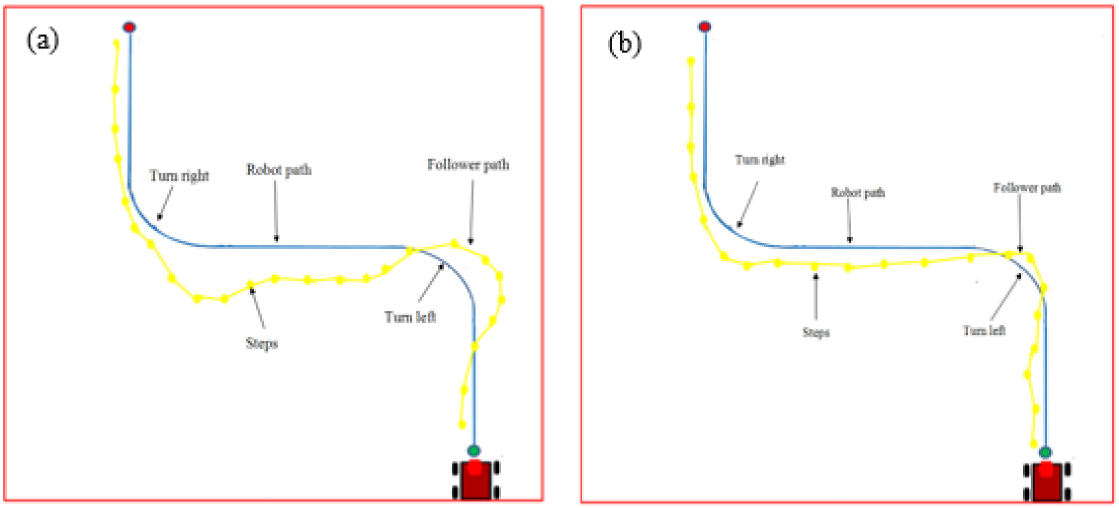


Figure (8.1a) Follower path in preliminary test, (b) Follower path in prototype (IV) test

1- By observing the follower's paths in figure (8.1a) (which is obtained from the analysis of the cumulative follower steps photo), the extent of the improvement can be observed. In the preliminary test, the followers exhibit considerable deviation to the right side out of the robot path when the robot turns left. A large deviation of the follower path in the middle and beginning of right rotation can also be observed. However, in the prototype (IV) test (final test) as shown in Figure (10.1b), it can be seen that the deviation has been significantly reduced. Also a decrease of the deviation in the middle of the path can be noted.

2- By observing Figure (10.2a) it is clear that there is fluctuation in the sensor's readings, because the rein is fixed and potentially works against the follower which causes some follower shaking and Staggering. However, when testing prototype IV, the fluctuation (follower reeling) of the sensors readings has been reduced, as shown in Figure (10.2b) and adds the conformable feeling.

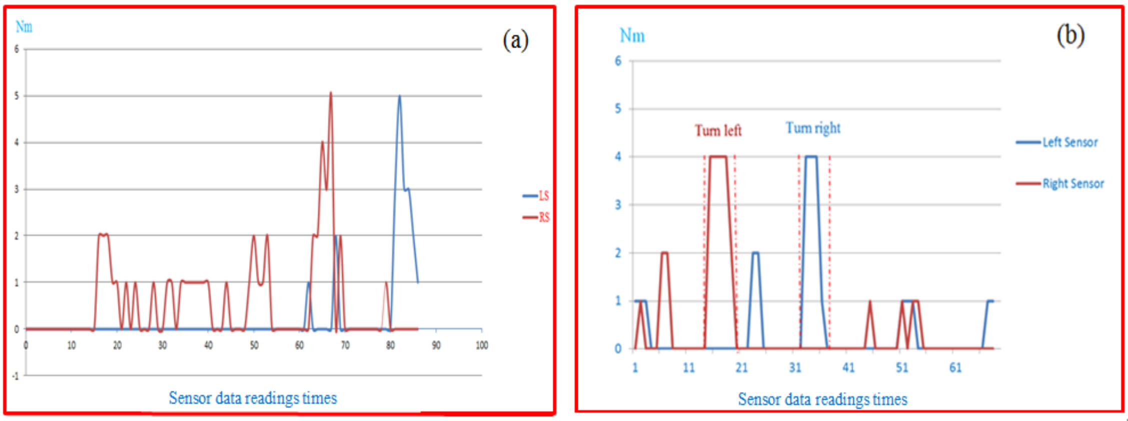


Figure (8.2a) Dataset of the one sample in preliminary test, (b) Dataset of the one sample in prototype (IV) test

Also in figures (8.2a, b), there is a difference between the readings of the tensile force. In the preliminary test, the tensile force increases in some other samples up to 8Nm, but in the prototype (IV) test it does not exceed 6 Nm for all samples, thus the tensile force is reduced.

8.3-Major Findings

During my research, many findings have been observed and it will present in the following points:

- The preliminary test carried out with fixed rein shows that there is a critical problem when robot turns left/right. This problem can be observed by looking to the deviation between the robot and the follower and this deviation in path may cause major risks for the follower especially in narrow places. To avoid this problem the research focused on knowing the specific place of the follower. In order to achieve that, many sensors have been planted to detect the follower's vertical and horizontal location with respect to the guiding robot.

- From the preliminary test it becomes clear that the participants are not confident which causes reeling and swings in movements. Moreover, the preliminary test shows the comfort level was higher when the robot moves forward, then turns.Thought right turns more comfortable than left turns.

- In the prototype (II) test, the speed selected for when the participants were located in the middle of the range was found by a mathematical equation .

- In the prototype (II) test, it was found that if the speed is more than 0.192m/s, it causes empty steps (the motor moves and the follower is unable to track the rein , a speed of greater than 0.192 m/s too high and must be avoided in normal use)

- In preliminary tests the sensor readings reached 8Nm; this is a consequence of the rein being fixed and working against the follower’s natural hand movement.

- After drawing and analysis the follower cumulative steps it appears that the left turns cause more deviation than turns right.

- In the test of the prototype (IV) tensile force values must be selected with great care, because when it is greater than 0.3Nm, any little movements for the follower will cause the rein moving and leads to confuse the follower.

- In prototype (IV) test, the rein moves to reduce the tensile force and doesn’t exceed 6 Nm.

- In General, participants still do some stagger and reeling with the intelligent rein before and after robot turn.

8.4-Conclusion

After the end of the research, we can conclude that it is possible to rely on the robot for helping the firefighters, where the ground is possible; also, it possible to rely on the rein for haptic signal transfer and it can convey a set of haptic messages to the firefighters. Also, the shared control system integrates: (i) the advantage of the human capability to recognize the environmental navigation, (ii) using the advantages of the robot to identify obstacles in the dark, noisy and dust areas. It can be confirmed that the haptic sense can be used as the optimal solution in some areas. Moreover, some points have been highlighted in the design and implementation of haptic intelligent rein that may help researchers in the future and take them in consideration to avoid mistakes and save time. The developed system has been tested and evaluated against the previous design of the rein, and both were compared .The paths of the previous and current system were compared to observe the difference between them, and note the great improvement in robot / follower paths, as well as by tracking the results of the tensile force sensors and drawing the results of one complete sensors cycle. The fluctuation which was observed in the preliminary test disappears in final test (prototype (IV). Also, the preliminary test sensors have 8, 9 Nm readings, which means that there is high tension between followers and rein. But the tensile force was reduced using the intelligent rein, which causing less fluctuation. This intelligent robotic rein continues works to know the follower position by using the encoder's value. As well as, the value of tensile force was used to move rein in the direction required for guiding the follower to follow the robot path in a safe and comfortable way. This happens by reducing the tensile force according the specific value. For example, if the tensile force is less than 0.3Nm, the rein remains without any action to allow the follower to do little inadvertently movements. If the tensile force becomes greater, the rein will move ±5° depending on follower's position. Or if tensile force goes between 0.3Nm and 2Nm that means, the tensile strength has to be reduced and the rein works to return the follower to zero point (to the first position of the rein in robot base middle). In this way, there is continues interaction between the follower and the robot.

Finally, we can say that this work demonstrates a new idea in the use of sensors to raise the level of robot human interaction, as well as to achieve automatous robot/ follower safe navigation.

8.5-Recommendations for Future Research

There are several aspects that can be improved in order to make future research on this topic more accurate and more meaningful.

1- In order to make useful control of the system, it must be connected to the robot operating system and through this connection; it is possible to decrease the speed of the robot when turning. This will result in restoring high comfort level to the follower especially in robot turning.

2- It is recommended to make metal system structure such as Aluminum to be reliable and also to prevent the damages during the test.

3- It is recommended to increase the robot weight to prevent the possible slip during the tests.

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Appendices

Appendix A Test1 forms

Appendix (A) Questionnaire form

Questionnaire form

Sample ( )

Name (Optional): ________________ Age: ______________ Height: ________________

Tensile strength force felling on forward, Right/ Left and Left/Right turn

* Tick (√) on the comfortable level you feel (1….5)

Forward

COMFORTABILITY	**UNCOMFORTABLE**		⇨	**COMFORTABLE**	
Comfortable Level	**1**	**2**	**3**	**4**	**5**
Selection					

Turn / Left

COMFORTABILITY	**UNCOMFORTABLE**		⇨	**COMFORTABLE**	
Comfortable Level	**1**	**2**	**3**	**4**	**5**
Selection					

Turn / Right

COMFORTABILITY	**UNCOMFORTABLE**		⇨	**COMFORTABLE**	
Comfortable Level	**1**	**2**	**3**	**4**	**5**
Selection					

Appendix (A) Participant Information Sheet

Participant Information Sheet: Development of an Intelligent Robotic Rein for Haptic Control and Interaction with Mobile Machines

Thank you for expressing your interest in taking part in this study. This study aims to observe how the user continues to follow the robot path after using shared intelligent control system between the prototype one and prototype two. You will be asked to follow the rein with your normal speed and focus in your confirmability through the test. We are aiming to recruit healthy adults with no current injuries or defects in forearm affecting in filling capacity, aged 18 years and above from staff and students of Sheffield Hallam University.

The task will be conducted in the sheaf building room 4114, main Campus, Sheffield Hallam University during February 2018. You will be asked to perform one session with two test trails one in each direction, each test trial take 2minute.

Once you arrive at the sheaf building room 4114, you will be given a full explanation about the study before any tests start. The researcher will answer any questions you may have related to the study. Your consent form and relevant background information will be collected.

The researcher will explain the whole experiment procedure. There will time for you to familiarise yourself on the experiment. After each test trial, the researcher will ask you to fill level of comfortability form(how tensile strengths you feel) , in spectrum from 1 to 5 in forward move and left/right turn .The trial will approximately 7 minute to complete. The researcher will contact you again if he needs to confirm some data. All digital and non-digital data will be protected and placed in a locked cabinet and only used for academic purposes. The data will be kept confidentiality for *ten years* after publication and anonymised, so no individual will be identifiable from it. No one will get access to the data without getting approval from you and the member of the research team. All data will be analysed and written up for conference presentations, journal articles and a dissertation. If you are keen to receive further information and results, the researcher will provide the following academic output and information. You are free to withdraw from this study at any time for any reasons and you are not required to give a reason.

Thank you very much for your interest, If you have any questions, please contact the researcher: Musstafa Elyounnss .

Appendix (A) consent form

SAMPLE PARTICIPANT CONSENT FORM

TITLE OF RESEARCH STUDY:

Please answer the following questions by ticking the response that applies

	YES	NO
1. I have read the Information Sheet for this study and have had details of the study explained to me.	☐	☐
2. My questions about the study have been answered to my satisfaction and I understand that I may ask further questions at any point.	☐	☐
3. I understand that I am free to withdraw from the study within the time limits outlined in the Information Sheet, without giving a reason for my withdrawal or to decline to answer any particular questions in the study without any consequences to my future treatment by the researcher.	☐	☐
4. I agree to provide information to the researchers under the conditions of confidentiality set out in the Information Sheet.	☐	☐
5. I wish to participate in the study under the conditions set out in the Information Sheet.	☐	☐
6. I consent to the information collected for the purposes of this research study, once anonymised (so that I cannot be identified), to be used for any other research purposes.	☐	☐

Participant's Signature: ____ Date: ___________

Participant's Name (Printed): ___________________________________

Contact details: ____

____

Researcher's Name (Printed): __________________________________

Researcher's Signature: ______________________________________

Researcher's contact details:
(Name, address, contact number of investigator)

Please keep your copy of the consent form and the information sheet together.

Appendix B Preliminary test Samples

LS= Left sensor (load cell), HS= Rein horizontal sensor (Encoder)

RS=Right sensor (load cell), VS = Rein vertical sensor (Encoder)

Appendix (B) Sample1

Preliminary test, samples

(Participants)

Order	Rein LS	Rein RS	Motor S	Rein HS	Rein VS
0	1	0	21	168	51
1	0	2	42	336	102
2	0	2	42	336	103
3	0	2	43	336	102
4	0	2	43	335	102
5	0	2	44	334	102
6	0	2	45	333	102
7	0	1	46	333	102
8	0	2	47	333	102
9	0	1	47	332	102
10	0	3	49	332	102
11	0	1	50	331	102
12	0	3	50	331	102
13	0	1	51	330	102
14	0	3	52	330	102
15	0	3	53	328	102
16	0	2	54	328	102
17	0	0	54	332	102
18	0	0	56	338	102
19	0	1	56	338	102
20	0	0	57	337	102
21	0	0	58	338	102
22	0	2	59	338	102
23	0	0	60	338	102
24	0	0	60	339	102
25	0	0	62	339	102
26	0	2	63	339	102
27	0	0	64	337	102
28	0	3	65	16	3
29	0	4	66	15	3
30	0	7	66	14	3
31	8	0	68	14	3
32	0	7	68	13	3
33	0	4	69	14	3
34	0	1	70	13	4
35	0	2	71	13	3
36	0	1	72	14	3
37	0	0	73	13	3
38	0	1	73	14	3
39	0	0	75	14	3
40	0	2	75	13	3
41	0	0	76	14	3

42	0	1	77	14	3
43	0	1	78	14	3
44	0	0	79	14	3
45	0	1	80	14	3
46	0	1	81	14	3
47	0	1	82	15	3
48	1	0	82	15	3
49	3	0	83	15	3
50	5	0	84	15	3
51	2	0	85	15	3
52	1	0	86	15	3
53	1	0	87	15	3
54	0	0	88	15	3
55	0	0	89	14	3
56	0	0	90	14	3
57	0	0	91	15	3
58	0	0	91	15	3
59	0	0	92	15	3
60	0	0	93	15	3
61	0	0	94	15	3
62	0	0	95	15	3
63	0	0	96	15	3

LS= Left sensor (load cell), HS= Rein horizontal sensor (Encoder)

RS=Right sensor (load cell), VS = Rein vertical sensor (Encoder)

Appendix (B) Sample2

Preliminary test, samples

(Participants)

Order	Rein LS	Rein RS	Motor S	Rein HS	Rein VS
0	0	0	229	188	182
1	2	0	97	15	4
2	3	2	97	15	4
3	0	0	97	15	4
4	0	2	97	15	4
5	0	2	97	15	4
6	0	0	97	15	4
7	0	2	97	15	4
8	0	2	97	15	4
9	0	2	97	15	4
10	0	2	97	15	4
11	0	0	97	15	4
12	0	2	97	15	4
13	0	2	97	15	4
14	0	2	97	15	4
15	0	2	97	15	4
16	0	4	97	15	4
17	0	0	97	15	4
18	0	0	97	15	4
19	0	0	97	15	4
20	0	0	97	15	4
21	0	0	97	15	4
22	0	0	97	15	4
23	0	0	97	15	4
24	0	0	97	15	4
25	0	0	97	15	4
26	0	0	97	15	4
27	4	0	97	15	5
28	4	2	97	05	4
29	0	0	97	05	4
30	0	3	97	05	4
30	0	4	97	05	4
32	0	7	97	05	4
33	0	4	97	05	4
34	0	0	97	05	4
35	0	2	97	05	4
36	0	0	97	05	4
37	0	0	97	05	4
38	0	0	97	05	4
39	0	0	97	05	4
40	0	0	97	05	4

40	0	0	97	05	4
42	0	0	97	05	4
43	0	0	97	05	4
44	0	0	97	05	4
45	0	0	97	05	4
46	0	0	97	05	4
47	0	0	97	05	4
48	0	0	97	05	4
49	0	0	97	05	4
50	0	0	97	05	4
50	0	2	97	05	4
52	0	2	97	05	5
53	0	2	97	05	4
54	3	2	97	05	4
55	5	2	97	05	4
56	0	2	97	05	4
57	0	2	97	05	4
58	0	2	97	05	4
59	0	2	97	05	5
60	0	2	97	05	4
61	0	2	97	05	4
62	0	2	97	05	4
63	0	2	97	05	4
64	0	2	97	05	4
65	0	2	97	05	4
66	0	2	97	05	4
67	0	2	97	05	4
68	0	2	97	05	4
69	0	0	97	05	4
70	0	0	97	05	4
71	0	0	97	05	4
72	0	0	97	05	4
73	0	0	97	05	4
74	2	0	97	05	4
75	0	0	97	05	4
76	0	0	97	05	4
77	0	0	97	05	4
78	0	0	97	05	4
79	0	0	97	05	4
80	0	0	97	05	4
81	0	0	97	05	4
82	0	0	97	05	4
83	0	0	97	05	4
84	0	0	97	05	4
85	0	0	97	05	4
86	0	0	97	05	4
0	0	0	97	05	4

1	0	0	97	05	4
2	0	0	97	05	4
3	0	0	97	05	4
4	0	0	97	06	4
5	0	0	97	05	4
6	0	0	97	05	4
7	0	0	97	05	4
8	0	0	97	05	4
9	0	0	97	05	4
10	0	0	97	05	4
11	0	0	97	05	4

LS= Left sensor (load cell), HS= Rein horizontal sensor (Encoder)

RS=Right sensor (load cell), VS = Rein vertical sensor (Encoder)

Appendix (B) Sample3

Preliminary test, samples

(Participants)

Order	Rein LS	Rein RS	Motor S	Rein HS	Rein VS
0	0	0	046	05	3
1	0	0	046	05	3
2	0	0	046	05	3
3	0	0	046	05	3
4	0	0	046	05	3
5	0	0	046	05	3
6	0	0	046	05	3
7	0	0	046	05	3
8	0	0	046	05	3
9	0	0	046	05	3
10	0	0	046	05	3
11	0	0	046	05	3
12	0	0	046	05	3
13	0	2	046	05	3
14	0	2	046	06	3
15	0	2	046	05	3
16	0	1	046	06	3
17	0	1	046	05	3
18	0	0	046	05	3
19	0	0	046	05	3
20	0	1	046	06	3
21	0	1	046	05	3
22	0	0	046	05	3
23	0	1	046	05	3
24	0	1	046	05	3
25	0	0	046	05	3
26	0	0	046	05	3
27	0	0	046	05	3
28	0	1	046	05	3
29	0	1	046	05	3
30	0	0	046	05	3
30	0	0	046	06	3
32	0	1	046	06	3
33	0	1	046	05	3
34	0	0	046	05	3
35	0	0	046	06	3
36	0	1	046	06	3
37	0	1	046	05	3
38	0	1	046	05	3
39	0	1	046	05	3
40	0	1	046	06	3

40	0	1	046	06	3
42	0	1	046	05	3
43	0	1	046	05	3
44	0	1	047	05	3
45	0	0	048	05	3
46	0	0	049	06	2
47	0	0	050	06	3
48	0	1	050	06	3
49	0	1	052	06	3
50	0	0	053	06	4
50	0	0	053	05	4
52	0	0	054	06	4
53	0	2	055	05	4
54	0	1	056	04	4
55	0	1	057	06	3
56	0	2	058	05	3
57	0	0	059	05	2
58	0	0	060	07	0
59	0	0	060	06	0
60	0	0	060	07	0
61	1	0	062	06	3
62	1	0	063	07	3
63	0	2	064	06	3
64	0	2	065	07	3
65	0	4	066	05	3
66	0	3	067	04	3
67	0	5	068	04	4
68	2	0	069	04	3
69	0	2	070	04	4
70	0	0	070	03	4
71	0	0	073	04	3
72	0	0	074	05	3
73	0	0	074	04	3
74	0	0	075	04	3
75	0	0	076	05	3
76	0	0	077	05	3
77	0	0	078	05	3
78	0	1	079	05	3
79	0	0	080	05	3
80	0	0	080	05	4
81	3	0	082	06	3
82	5	0	083	05	4
83	3	0	084	06	3
84	3	0	085	06	3
85	2	0	086	06	3
86	0	0	087	06	3

LS= Left sensor (load cell), HS= Rein horizontal sensor (Encoder)

RS=Right sensor (load cell), VS = Rein vertical sensor (Encoder)

Appendix (B) Sample4

Preliminary test, samples

(Participants)

Order	Rein LS	Rein RS	Motor S	Rein HS	Rein VS
0	0	0	088	06	3
1	1	0	088	06	2
2	1	1	088	06	3
3	0	2	088	06	3
4	2	0	088	06	2
5	0	0	088	06	3
6	0	0	088	06	3
7	0	0	088	06	3
8	0	2	088	06	2
9	0	4	088	06	3
10	0	0	088	06	3
11	0	0	088	06	2
12	2	0	088	06	3
13	2	0	088	06	2
14	0	0	088	06	2
15	0	0	088	06	2
16	0	0	088	06	3
17	0	3	088	06	2
18	0	3	088	06	3
19	0	4	088	06	2
20	0	0	088	06	2
21	0	0	088	06	2
22	0	0	088	06	3
23	0	0	088	06	2
24	0	0	088	06	2
25	0	0	088	06	3
26	0	0	088	06	2
27	0	0	088	06	2
28	0	2	088	06	2
29	0	0	088	06	3
30	0	0	088	06	2
30	0	3	088	06	3
32	3	5	088	06	2
33	3	8	088	06	2
34	0	7	088	06	2
35	0	2	088	06	2
36	0	0	088	06	3
37	0	0	088	06	3
38	0	0	088	06	3
39	0	0	088	06	2
40	0	0	088	06	3

40	0	0	088	06	2
42	0	0	088	06	3
43	0	0	088	06	2
44	0	0	088	06	3
45	0	0	088	06	2
46	0	0	088	06	3
47	0	0	088	06	2
48	0	0	088	07	2
49	1	0	088	06	3
50	0	0	088	06	2
50	0	0	088	06	2
52	0	0	088	06	2
53	2	0	088	06	2
54	4	0	088	06	2
55	6	0	088	06	3
56	3	0	088	06	3
57	0	0	088	06	2
58	0	0	088	06	2
59	0	0	088	06	2
60	0	0	088	06	2
61	0	0	088	06	2
62	0	0	088	06	3
63	0	0	088	06	3
64	0	0	088	06	2
65	0	0	088	06	3
66	0	0	088	06	2
67	0	0	088	06	2
68	0	0	088	06	3
69	0	0	088	06	2
70	0	0	088	06	2
71	0	0	088	06	3
72	0	0	088	06	2
73	2	0	088	06	2
74	2	0	088	06	3
75	2	0	088	06	3
76	2	0	088	06	2
77	0	0	088	06	3
78	0	0	088	06	3
79	0	0	088	06	3
80	0	0	088	06	2
81	0	0	088	06	3
82	0	0	088	06	2
83	0	0	088	06	2
84	0	0	088	06	2
85	0	0	088	06	2
86	0	0	088	06	2
0	0	0	088	06	3

1	0	0	088	06	3
2	0	0	088	06	2
3	0	0	088	06	3
4	0	0	088	06	3
5	0	0	088	06	2
6	0	0	088	06	2
7	0	0	088	06	3
8	0	0	088	06	3
9	0	0	088	06	2
10	0	0	088	06	2
	0	0			

LS= Left sensor (load cell), HS= Rein horizontal sensor (Encoder)

RS=Right sensor (load cell), VS = Rein vertical sensor (Encoder)

Appendix (B) Sample5

Preliminary test, samples

(Participants)

Order	Rein LS	Rein RS	Motor S	Rein HS	Rein VS
0	0	0	20	04	3
1	0	0	20	05	3
2	0	0	20	04	3
3	0	0	20	04	3
4	0	0	20	04	3
5	0	0	20	04	4
6	0	2	20	04	3
7	0	0	20	04	4
8	0	2	09	05	4
9	0	0	09	04	4
10	0	0	09	04	4
11	0	2	09	04	4
12	0	0	09	04	4
13	0	2	09	04	4
14	0	0	08	04	4
15	0	0	08	05	0
16	0	0	08	05	0
17	0	0	08	05	0
18	0	0	08	05	0
19	0	0	08	05	2
20	0	0	2	30	3
21	0	0	07	05	3
22	0	0	07	05	4
23	0	2	07	04	4
24	0	4	07	04	4
25	0	6	07	02	4
26	2	8	06	02	4
27	0	7	07	02	4
28	0	3	06	02	4
29	0	0	06	02	4
30	0	0	06	02	4
30	0	0	06	02	2
32	0	0	06	04	0
33	0	0	06	04	4
34	0	0	05	04	4
35	0	0	05	04	2
36	0	0	05	05	4
37	7	0	05	05	4
38	3	0	05	04	2
39	0	0	05	05	4
40	1	1			

40	0	0	046	05	3
42	0	0	046	05	3
43	0	0	046	05	3
44	0	0	046	05	3
45	0	0	046	05	3
46	0	0	046	06	3
47	0	4	046	06	3
48	0	0	046	05	3
49	0	4	046	05	3
50	0	0	046	06	3
50	0	0	046	06	3
52	0	2	046	05	3
53	0	0	046	05	3
54	0	2	046	05	3
55	0	0	046	06	3
56	0	0	046	06	3
57	0	0	046	05	3
58	0	0	046	05	3
59	0	0	047	05	3
60	0	0	048	05	3
61	0	0	049	06	2
62	0	0	050	06	3
63	0	0	050	06	3
64	0	2	052	06	3
65	0	2	053	06	4
66	0	2	053	05	4
67	0	2	054	06	4
68	0	2	055	05	4
69	0	3	056	04	4
70	0	0	057	06	3
71	0	0	058	05	3
72	0	0	059	05	2
73	0	0	060	07	0
74	0	0	060	06	0
75	0	0	060	07	0
76	0	0	062	06	3
77	0	0	063	07	3
78	5	0	064	06	3
79	3	0	065	07	3
80	0	0	066	05	3
81			067	04	3
82	0	0	068	04	4
83	0	0	069	04	3
84	0	0	070	04	4
85	0	0	070	03	4
86	0	0	073	04	3

Appendix C Prototype (I)

Appendix (C) Prototype (I)

1- Photo of EMS22A-Non-contacting Absolute Encoder

EMS22A-Non-contacting Absolute Encoder (adapted from, Bourns, 2014)

Encoder pin configuration there are seven pins, each one of these pins describe one function, when encoder use

Output Type	Pin1 (D1)	Pin 2 (CLK)	Pin 3	Pin4(DO)	Pin5	Pin6
Absolute	Digital Input	CLOCK	GND	Digital Output	VCC*	CS

Encoder pin configuration

2-Encoder (I), my RIO connection

Encoder (I) is connected to my RIO via number of pins as shown in design block diagram figure (4.2), for encoder (I) CS pin 6 is connected to DIO1 pin 13 in my RIO port A to select encoder chip, VCC pin 5 in encoder (I) is connected to 3.3V pin 33 in my RIO, DIGITAL OUTPUT pin4in encoder (I) is connected to DIO4 pin 19 in myRIO, GND pin 3 of encoder (I) is connected to GND pin 8 of my RIO, and CLOCK pin 2 of encoder (I) is connected to DIO2 pin 15 of my RIO.

3-Encoder (II) my RIO connection

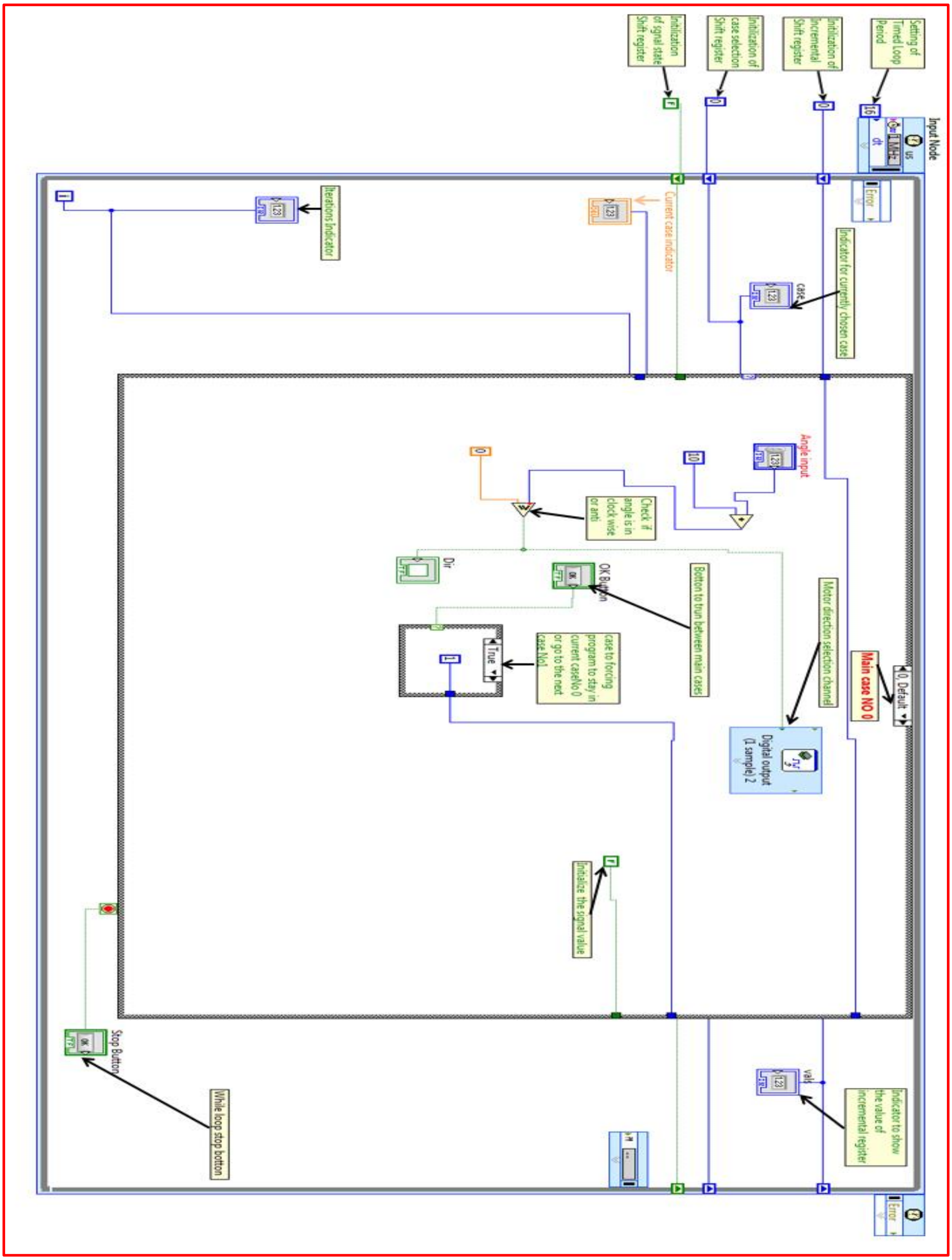
Encoder (II) is connected to my RIO via number of pins as shown in design block diagram figure (4.2), for encoder (II) CS pin 6 is connected to DIO1 pin 13 in my RIO port A to select encoder chip, VCC pin 5 in encoder (II) is connected to 3.3V pin 33 in my RIO, DIGITAL OUTPUT pin 4 in encoder (II) is connected to DIO3 pin 17 in myRIO, GND pin 3 of encoder (II) is connected to GND pin 8 of my RIO, and CLOCK pin 2of encoder (II) is connected to DIO2 pin 15 of my RIO.

4-Prototype (I) system start-up

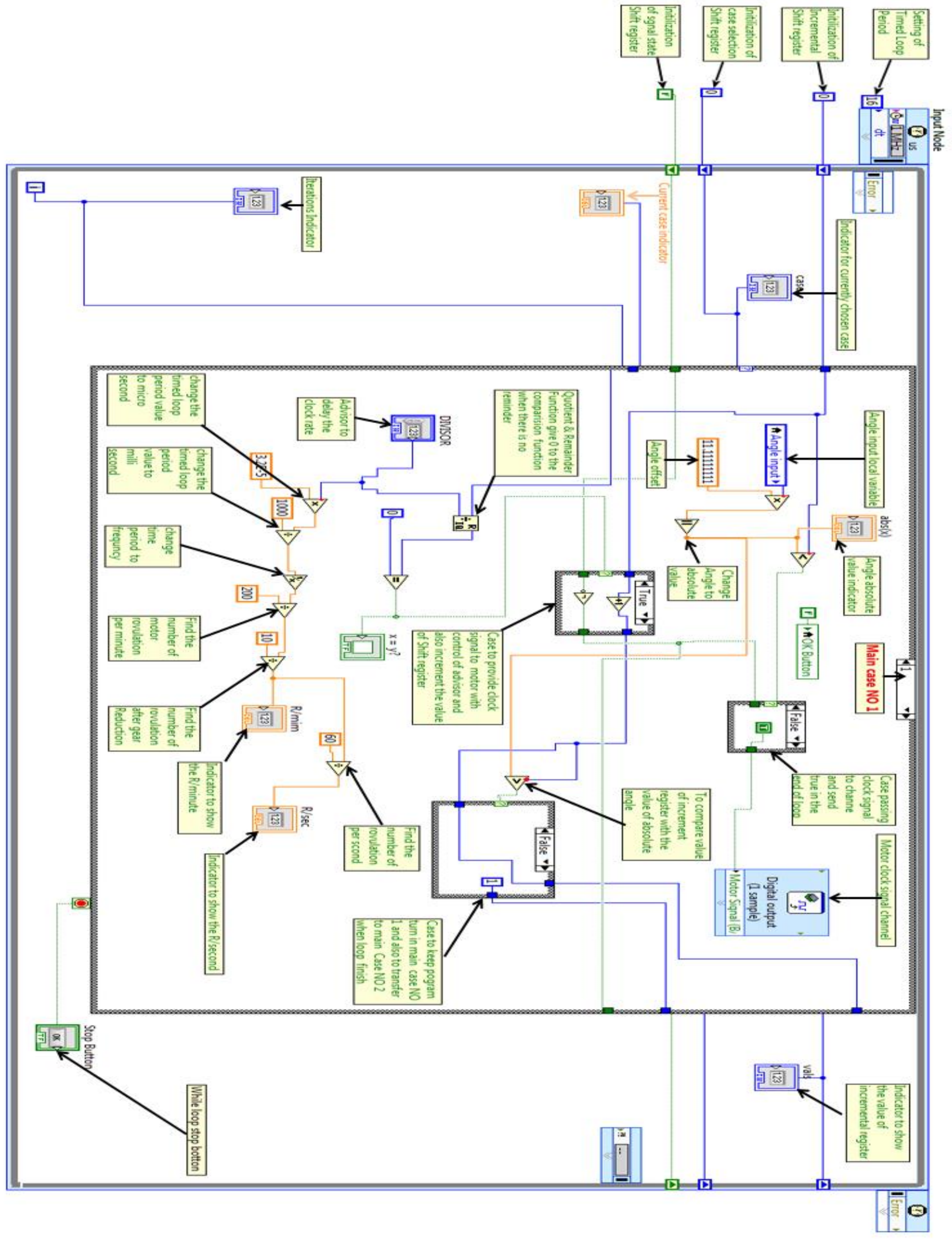
To start-up the prototype (I), must follow a plan of actions, which starts by system hardware connection and making sure sensors bodies and heads are connected to the metal plates as the first step. In the second step, the plates are connecting to the rein base which is also connected to the wooden base. In the third step, connect the sensors (encoders) to the data acquisition system (my RIO) via the data bus. Furthermore, the RIO is connected to power and PC host computer by USB. The data will flow from the sensors to the PC via myRIO, the function of myRIO is to give start-up signals to the sensor and receive data from the sensor. Another stage in the software side starts by install and running lab VIEW program to identify my RIO and receive process and monitor data for control and system test

Appendix D LabVIEW Programs

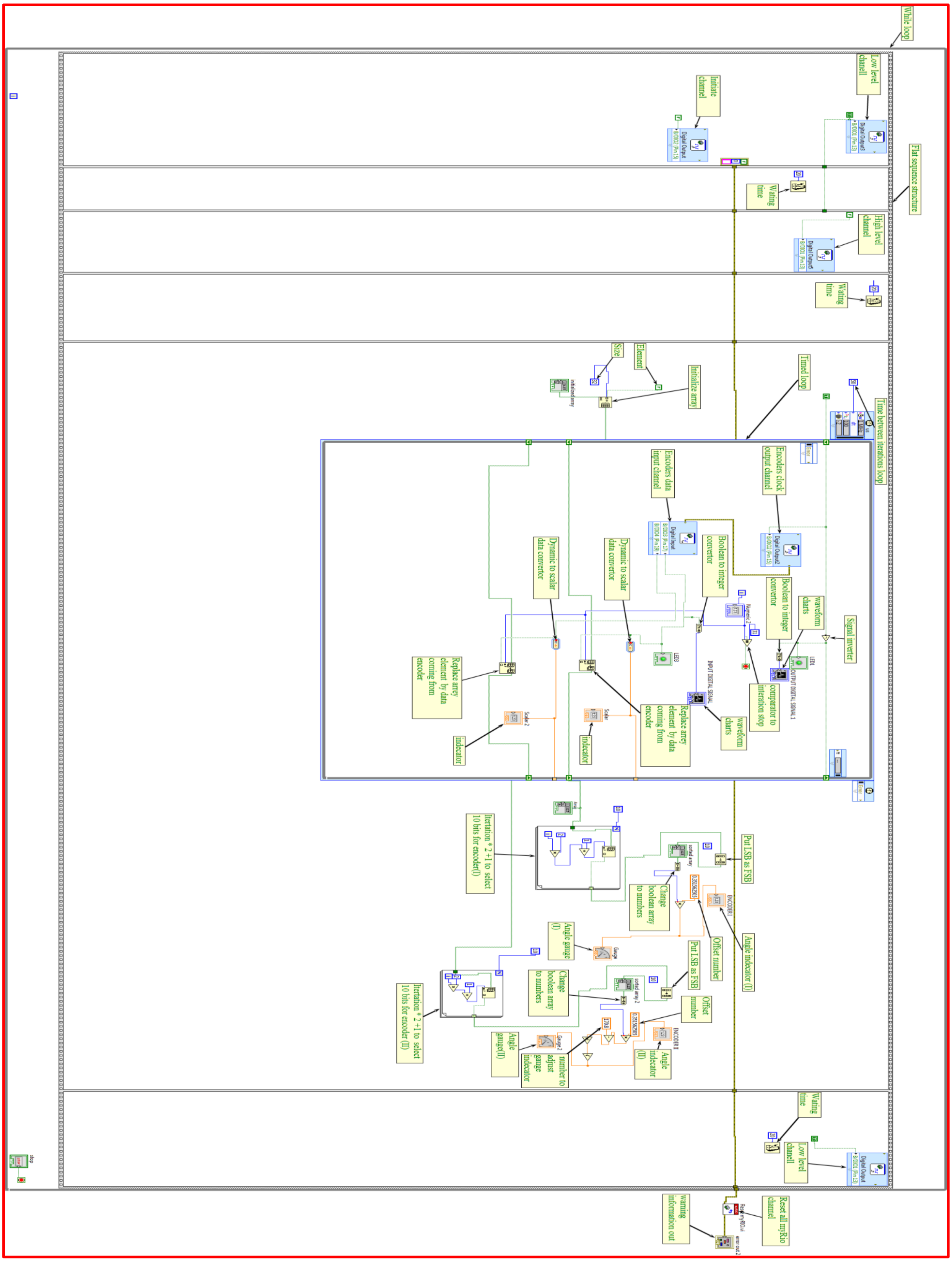
Appendix (D) Motor moving LabVIEW **main** program case 0



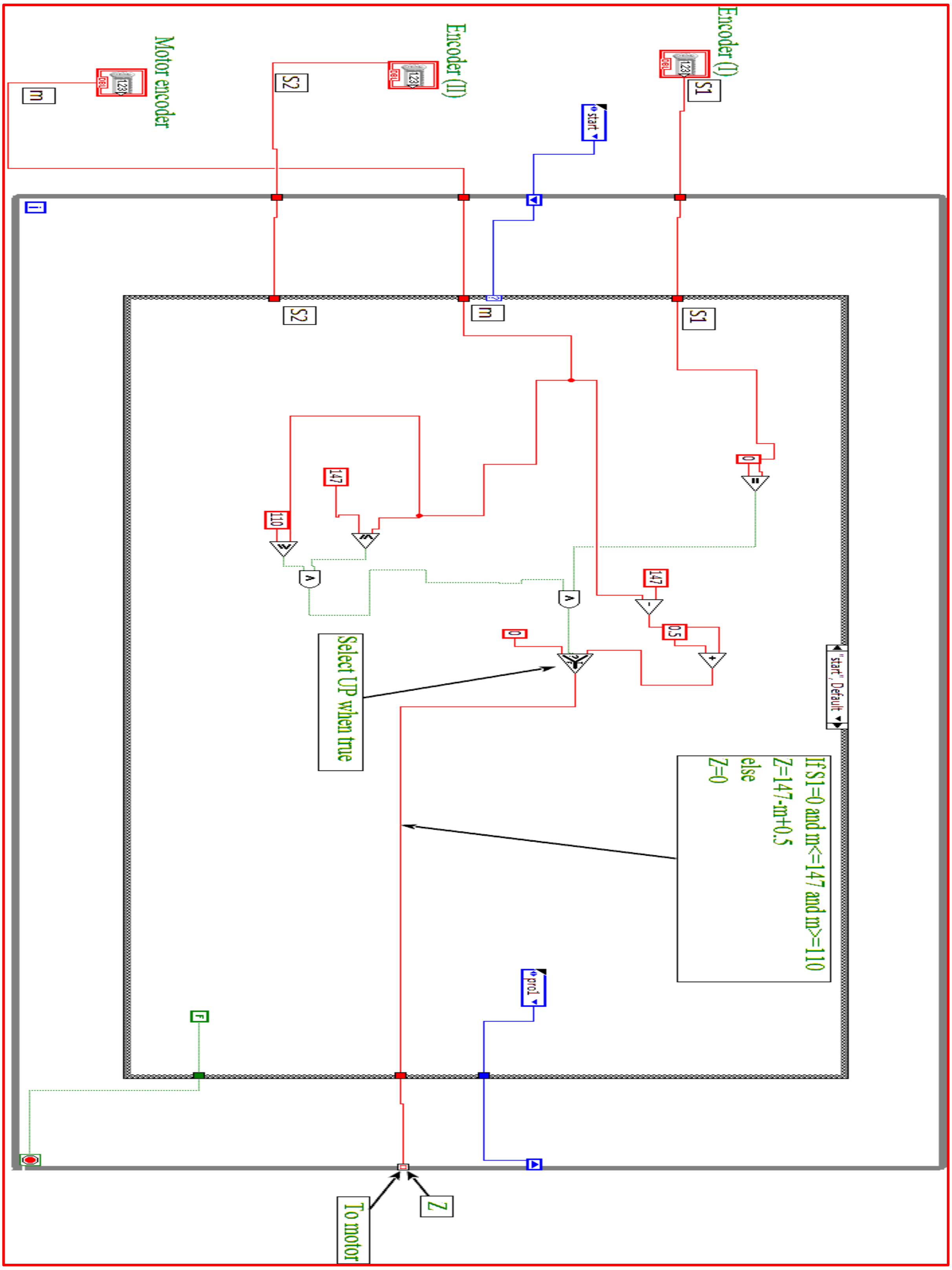
Appendix (D) Motor moving LabVIEW **main** program case 1



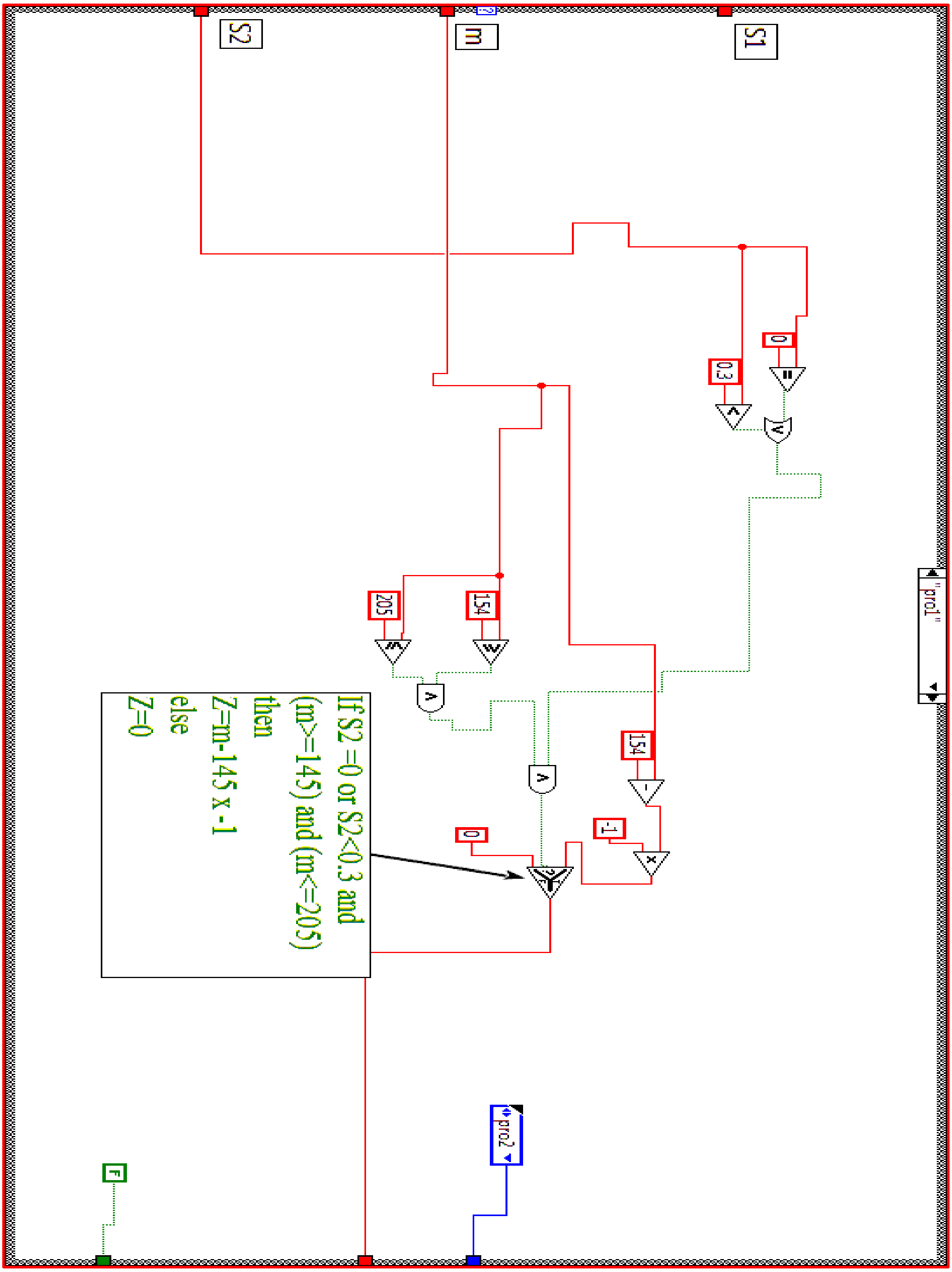
Appendix (D) Sensors LabVIEW program



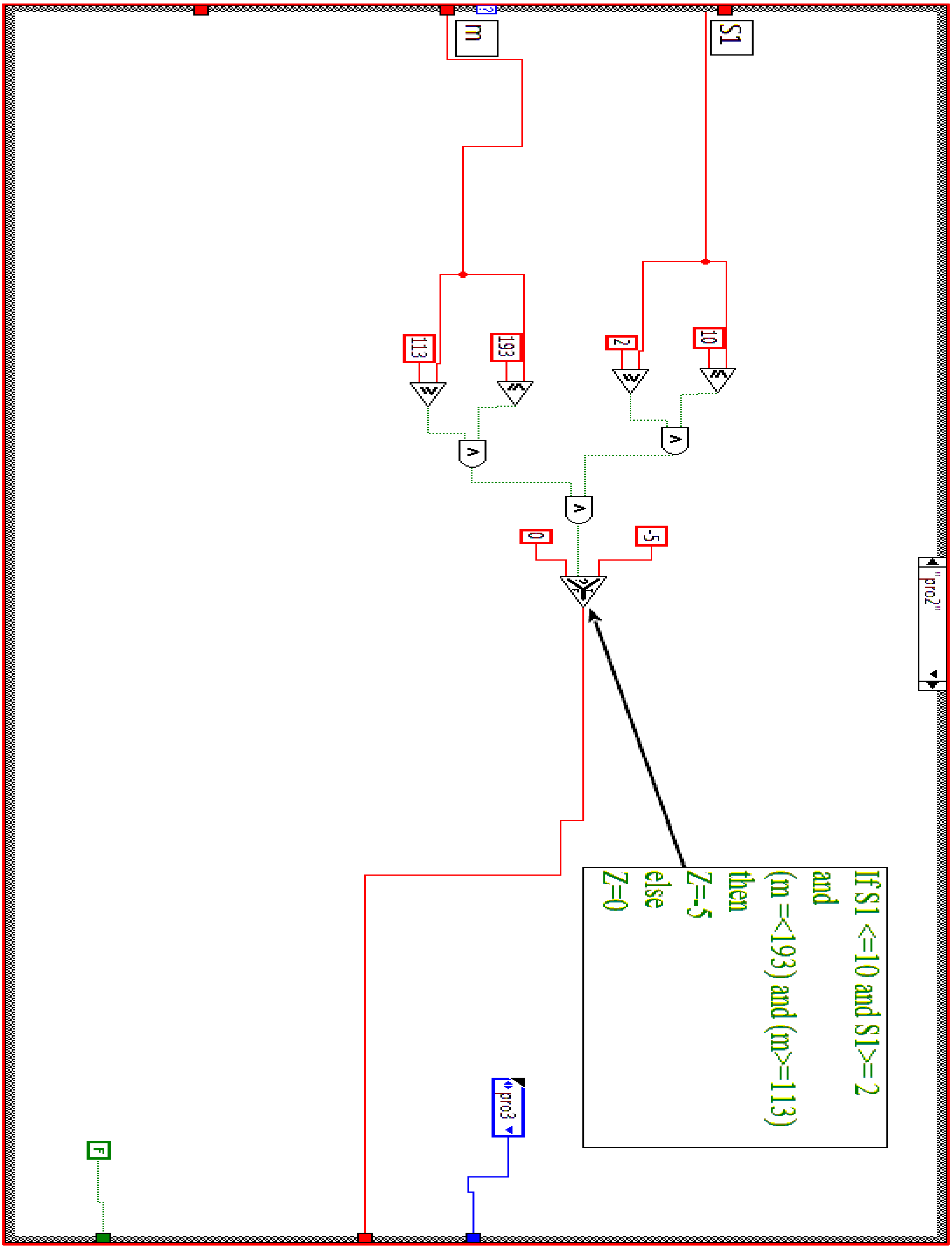
Appendix (D) Motor load cell response case (1)



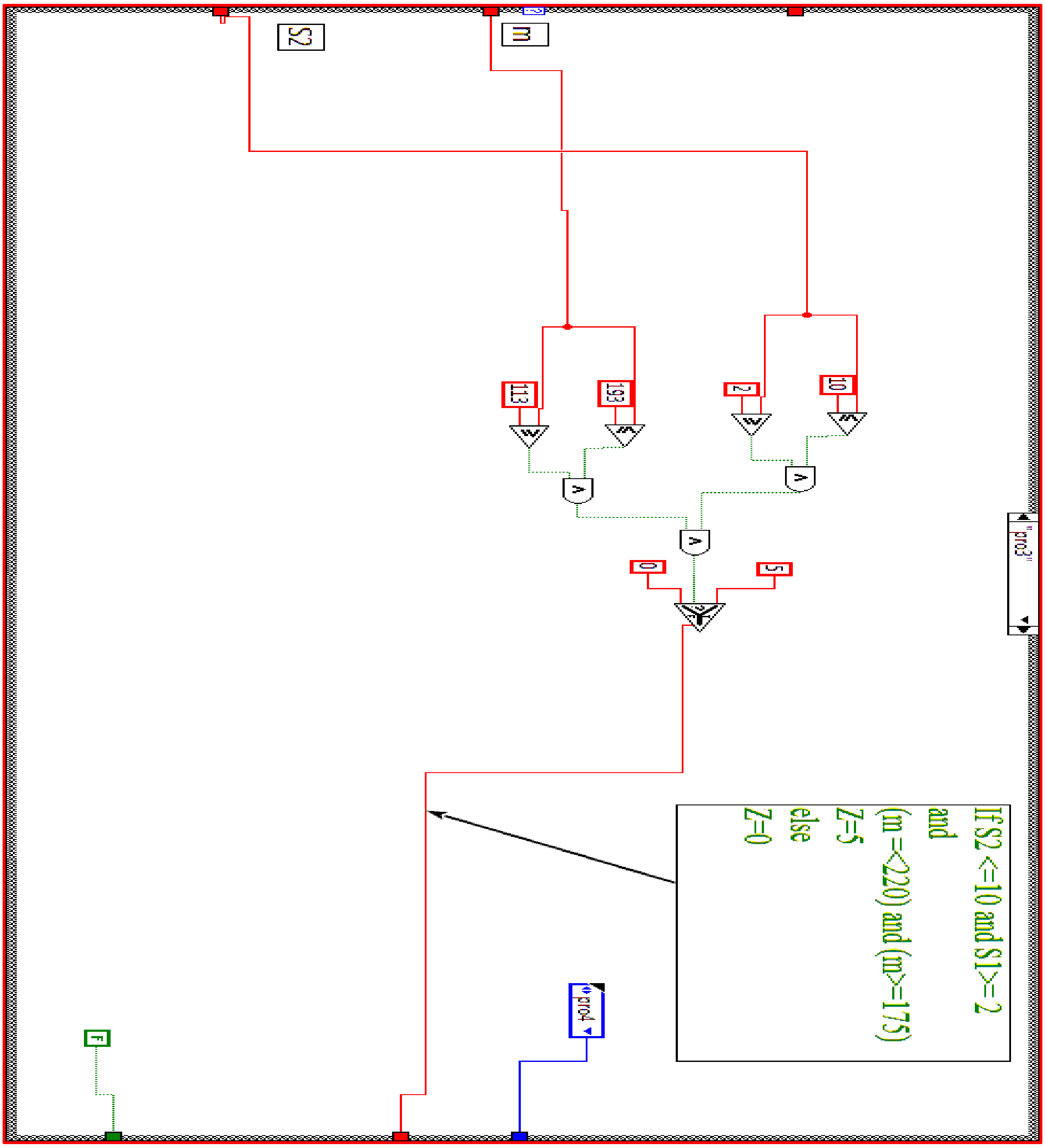
Appendix (D) Motor load cell response case (2)



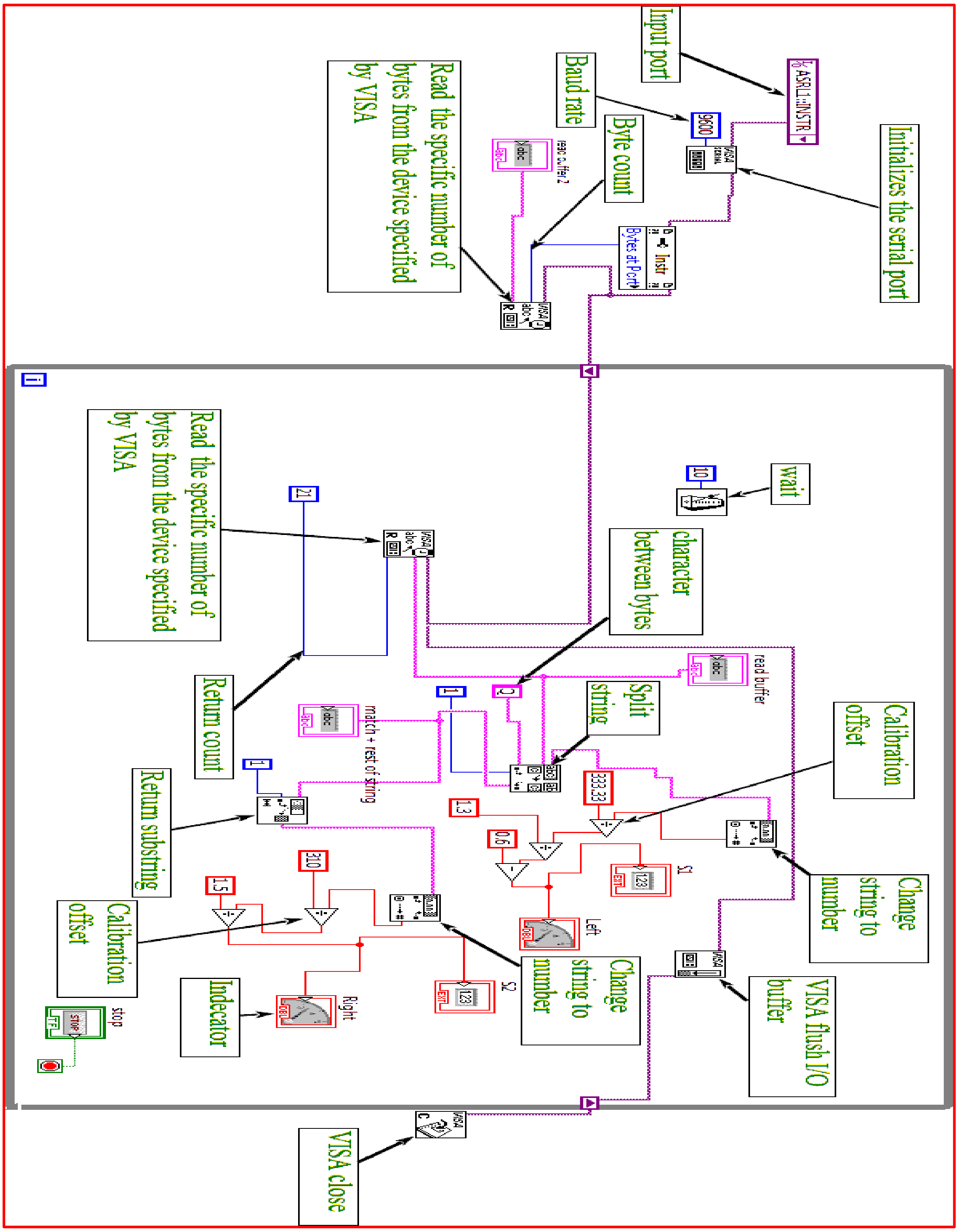
Appendix (D) Motor load cell response case (3)



Appendix (D) Motor load cell response case (4)



Appendix (D) load cell LabVIEW program



Appendix E Motor/Driver selection/Specifications/Connections

Appendix (E) Electrical Specification:23 HSX-306

Uni-polar operation Bi-polar operation

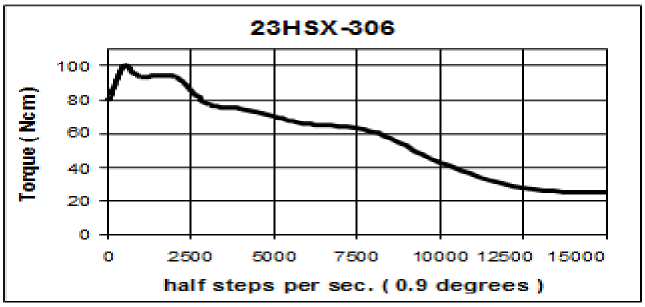
motor type	Resistance per phase ohms	Current per phase Amps	Inductance per phase mH
23HSX-306	1.1	3.0	1.7

Current / phase Series connection Amps	Current / phase Parallel connection Amps
2.1	4.2 max.

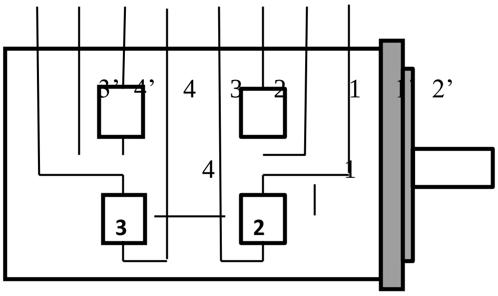
Mechanical Specification: 1.8 degree high performance 23HSX-306 stepper motor

motor type	length 'L' mm	Shaft diameter ' Ds ' Mm	number of leads	mass Kg	Uni-polar Holding Torque Ncm	Bi-polar Holding Torque Ncm	Rotor Inertia Kgcm ^{2}
23HSX-306	78.5	8.0	8	1.0	125	163	0.34

Typical performance 23HSX-306 stepper motor

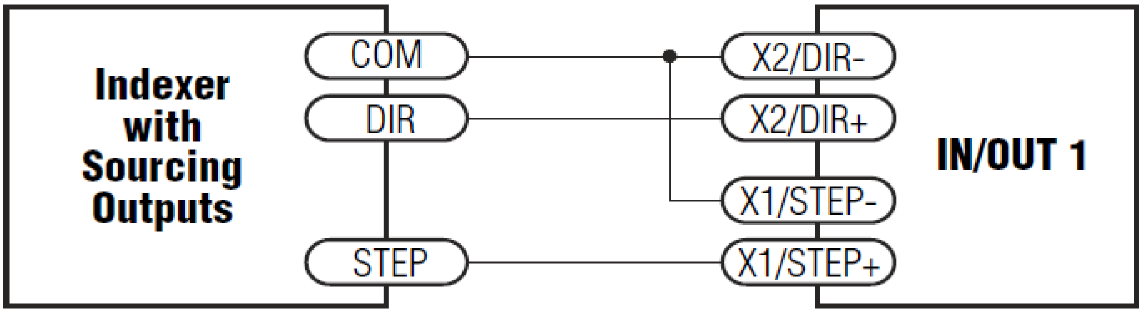


34 HSX stepper motor lead colours:

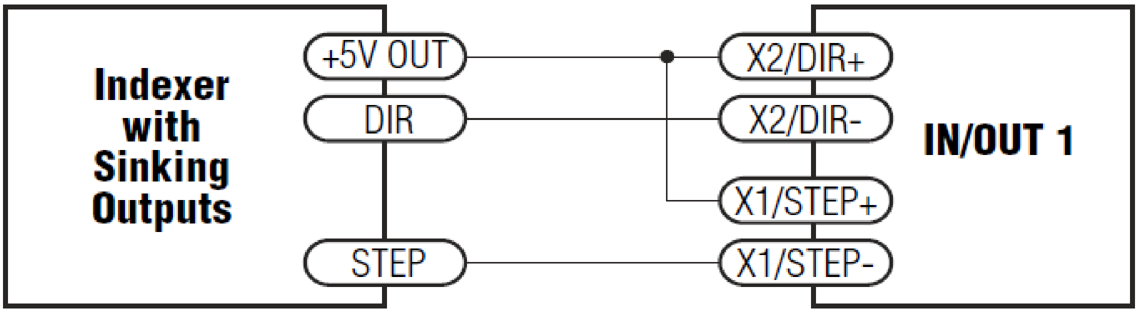


Motor Types	lead or terminal identification							
Lead identity	1	1’	2’	2	3	3’	4’	4
23HSX 306	Red	Red/ White	Yellow/ White	Yellow	Orange	Orange/ White	Brown/ White	Brown

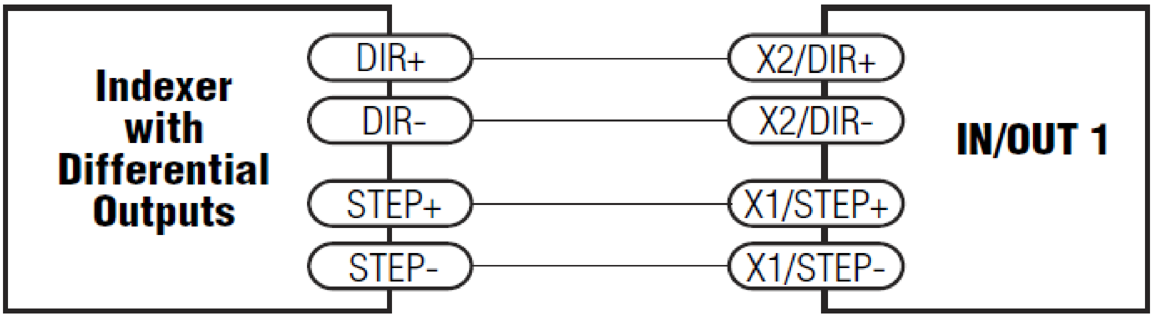
Appendix (E) Motor/driver connection



Connecting to indexer with Sourcing Outputs



Connecting to Indexer with Sinking Outputs



Appendix (E) Motor specification

Motor 23 HS series do 200 step /rev in full step driver
And do 400 step/ rev in half step driver
Continuous output torque 6 Nm at 6000 half step
Maximum continuous torque is 10 Nm
Mass is 1, 76 kg
Efficiency 95%
Gear boxIP57-M01
No of stages 1
Gear ratio 10:1
Max continuous torque 9
Maximum peak torque is 13.5
Efficiency 92%
Mass 660 g

Appendix F Prototype (II)

Appendix (F) Prototype (II)

1-Connecting steppers motor with the driver

After selecting the appropriate stepper motor in terms of torque and speed, as well as selecting the drive that provides the appropriate voltage and current to the motor, the motor is connected to the driver ST5-Q-NN. The function of this driver is to provide appropriate power to stepper motor as well as the necessary signals to choose a specific type of movement mode with the appropriate speed and direction. The motor is connected in parallel (when end of each coil is connected to the same point), and eight lead motors can be connected in two ways: series and parallel, series operation gives less torque at high speeds. For this application, the motor is connected in parallel to get high torque at low speed

2- Connection Motor driver to myRIO (Port B)

Driver ST5-Q-NN	myRIO	uses
X1/STEP+	5VCC	
X2/DIR+	5VCC	
X1/STEP-	DIO8 pin 27	Used for number of steps control
X2/DIR	DIO5 pin 21	Used to control the direction of motor rotation
GND	GND pin 8	Ground

3- Motor Encoder my RIO (Port A) connection

Motor Encoder	myRIO	uses
CLK	DIO2 pin 15	Clock to encoder
GND	GND pin 8	Ground
D/OUT	DIO0 pin 11	Receive data from encoder
VCC	3.3V pin 33	Power to encoder
CS	DIO1 pin 13	Select the encoder chip

Appendix G Prototype (IV)

LS= Left sensor (load cell), HS= Rein horizontal sensor (Encoder)

RS=Right sensor (load cell), VS = Rein vertical sensor (Encoder)

Appendix (G) Sample1

Seared control system test, samples (participant's)

Order	Rein LS	Rein RS	Motor S	Rein HS	Rein VS
0	1	0	21	168	51
1	1	1	42	336	102
2	1	0	42	336	103
3	0	0	43	336	102
4	0	0	43	335	102
5	0	2	44	334	102
6	0	2	45	333	102
7	0	0	46	333	102
8	0	0	47	333	102
9	0	0	47	332	102
10	0	0	49	332	102
11	0	0	50	331	102
12	0	0	50	331	102
13	0	0	51	330	102
14	0	4	52	330	102
15	0	4	53	328	102
16	0	4	54	328	102
17	0	4	54	332	102
18	0	2	56	338	102
19	0	0	56	338	102
20	0	0	57	337	102
21	0	0	58	338	102
22	2	0	59	338	102
23	2	0	60	338	102
24	0	0	60	339	102
25	0	0	62	339	102
26	0	0	63	339	102
27	0	0	64	337	102
28	0	0	65	16	3
29	0	0	66	15	3
30	0	0	66	14	3
31	0	0	68	14	3
32	4	0	68	13	3
33	4	0	69	14	3
34	4	0	70	13	4
35	1	0	71	13	3
36	0	0	72	14	3
37	0	0	73	13	3
38	0	0	73	14	3
39	0	0	75	14	3
40	0	0	75	13	3
41	0	0	76	14	3
42	0	0	77	14	3

43	0	0	78	14	3
44	0	1	79	14	3
45	0	0	80	14	3
46	0	0	81	14	3
47	0	0	82	15	3
48	0	0	82	15	3
49	0	0	83	15	3
50	1	1	84	15	3
51	1	0	85	15	3
52	1	1	86	15	3
53	0	1	87	15	3
54	0	0	88	15	3
55	0	0	89	14	3
56	0	0	90	14	3
57	0	0	91	15	3
58	0	0	91	15	3
59	0	0	92	15	3
60	0	0	93	15	3
61	0	0	94	15	3
62	0	0	95	15	3
63	0	0	96	15	3

LS= Left sensor (load cell), HS= Rein horizontal sensor (Encoder)

RS=Right sensor (load cell), VS = Rein vertical sensor (Encoder)

Appendix (G) Sample2

Seared control system test, samples (participant's)

Order	Rein LS	Rein RS	Motor S	Rein HS	Rein VS
0	0	0	229	188	182
1	1	0	97	15	4
2	0	2	97	15	4
3	0	0	97	15	4
4	0	0	97	15	4
5	0	0	97	15	4
6	0	2	97	15	4
7	0	2	97	15	4
8	0	0	97	15	4
9	0	0	97	15	4
10	0	0	97	15	4
11	0	0	97	15	4
12	0	0	97	15	4
13	0	0	97	15	4
14	0	0	97	15	4
15	0	0	97	15	4
16	0	0	97	15	4
17	0	0	97	15	4
18	0	0	97	15	4
19	0	0	97	15	4
20	0	0	97	15	4
21	0	0	97	15	4
22	0	0	97	15	4
23	0	0	97	15	4
24	0	0	97	15	4
25	0	0	97	15	4
26	0	0	97	15	4
27	0	0	97	15	5
28	0	2	97	15	4
29	0	0	97	15	4
30	0	3	97	15	4
31	2	4	97	15	4
32	2	6	97	15	4
33	0	6	97	15	4
34	0	1	97	15	4
35	0	2	97	15	4
36	0	0	97	15	4
37	0	0	97	15	4
38	0	0	97	15	4
39	0	0	97	15	4
40	0	0	97	15	4
41	0	0	97	15	4
42	0	0	97	15	4

43	0	0	97	15	4
44	5	0	97	15	4
45	5	0	97	15	4
46	5	0	97	15	4
47	5	0	97	15	4
48	0	0	97	15	4
49	0	0	97	15	4
50	0	0	97	15	4
51	0	0	97	15	4
52	0	0	97	15	5
53	0	0	97	15	4
54	0	0	97	15	4
55	0	0	97	15	4
56	0	0	97	15	4
57	1	0	97	15	4
58	0	0	97	15	4
59	0	0	97	15	5
60	0	0	97	15	4
61	0	0	97	15	4
62	0	0	97	15	4
63	0	0	97	15	4
64	0	0	97	15	4
65	0	0	97	15	4
66	0	0	97	15	4
67	0	0	97	15	4
68	0	0	97	15	4
69	0	0	97	15	4
70	1	0	97	15	4
71	0	2	97	15	4
72	0	0	97	15	4
73	0	0	97	15	4
74	0	0	97	15	4
75	0	2	97	15	4
76	0	2	97	15	4
77	0	0	97	15	4
78	0	0	97	15	4
79	0	0	97	15	4
80	0	0	97	15	4
81	0	0	97	15	4
82	0	0	97	15	4
83	0	0	97	15	4
84	0	0	97	15	4
85	0	0	97	15	4
86	0	0	97	15	4
87	0	0	97	15	4
88	0	0	97	15	4
89	0	0	97	15	4
90	0	0	97	15	4
91	0	0	97	16	4

92	0	0	97	15	4
93	0	0	97	15	4
94	0	0	97	15	4
95	0	0	97	15	4
96	0	0	97	15	4
97	0	2	97	15	4
98	0	0	97	15	4

LS= Left sensor (load cell), HS= Rein horizontal sensor (Encoder)

RS=Right sensor (load cell), VS = Rein vertical sensor (Encoder)

Appendix (G) Sample3

Seared control system test, samples (participant's)

Order	Rein LS	Rein RS	Motor S	Rein HS	Rein VS
0	0	0	146	15	3
1	0	1	146	15	3
2	1	1	146	15	3
3	2	0	146	15	3
4	0	0	146	15	3
5	0	0	146	15	3
6	0	0	146	15	3
7	0	0	146	15	3
8	0	0	146	15	3
9	0	0	146	15	3
10	0	0	146	15	3
11	0	0	146	15	3
12	0	0	146	15	3
13	0	0	146	15	3
14	0	0	146	16	3
15	0	0	146	15	3
16	0	0	146	16	3
17	0	0	146	15	3
18	0	0	146	15	3
19	3	0	146	15	3
20	2	0	146	16	3
21	2	5	146	15	3
22	0	6	146	15	3
23	0	6	146	15	3
24	0	1	146	15	3
25	0	0	146	15	3
26	0	0	146	15	3
27	0	0	146	15	3
28	0	1	146	15	3
29	0	0	146	15	3
30	0	0	146	15	3
31	0	0	146	16	3
32	0	0	146	16	3
33	0	0	146	15	3
34	0	0	146	15	3
35	4	0	146	16	3
36	4	0	146	16	3
37	0	0	146	15	3
38	0	0	146	15	3
39	0	0	146	15	3
40	0	0	146	16	3
41	0	0	146	16	3
42	0	0	146	15	3

43	0	0	146	15	3
44	0	1	147	15	3
45	0	0	148	15	3
46	0	0	149	16	2
47	0	0	150	16	3
48	0	0	150	16	3
49	0	1	152	16	3
50	0	2	153	16	4
51	0	1	153	15	4
52	0	1	154	16	4
53	0	2	155	15	4
54	0	0	156	14	4
55	0	0	157	16	3
56	0	0	158	15	3
57	0	0	159	15	2
58	0	0	160	17	1
59	0	0	161	16	1
60	0	0	161	17	1
61	0	0	162	16	3
62	0	0	163	17	3
63	0	0	164	16	3
64	0	0	165	17	3
65	0	0	166	15	3
66	0	0	167	14	3
67	0	0	168	14	4
68	0	0	169	14	3
69	0	0	170	14	4
70	0	0	171	13	4
71	0	1	173	14	3
72	1	1	174	15	3
73	2	0	174	14	3
74	0	0	175	14	3
75	0	0	176	15	3
76	0	0	177	15	3
77	0	0	178	15	3
78	0	0	179	15	3
79	0	0	180	15	3
80	0	0	181	15	4
81	0	0	182	16	3
82	0	0	183	15	4
83	0	0	184	16	3
84	0	0	185	16	3
85	0	0	186	16	3
86	0	0	187	16	3

LS= Left sensor (load cell), HS= Rein horizontal sensor (Encoder)

RS=Right sensor (load cell), VS = Rein vertical sensor (Encoder)

Appendix (G) Sample4

Seared control system test, samples (participant's)

Order	Rein LS	Rein RS	Motor S	Rein HS	Rein VS
0	0	0	188	16	3
1	0	1	188	16	2
2	2	2	188	16	3
3	0	2	188	16	3
4	0	0	188	16	2
5	0	0	188	16	3
6	0	0	188	16	3
7	0	0	188	16	3
8	0	0	188	16	2
9	0	0	188	16	3
10	0	2	188	16	3
11	1	0	188	16	2
12	0	0	188	16	3
13	0	0	188	16	2
14	0	0	188	16	2
15	0	0	188	16	2
16	0	0	188	16	3
17	0	0	188	16	2
18	0	0	188	16	3
19	0	0	188	16	2
20	0	0	188	16	2
21	0	0	188	16	2
22	0	0	188	16	3
23	0	0	188	16	2
24	0	0	188	16	2
25	0	0	188	16	3
26	0	0	188	16	2
27	0	0	188	16	2
28	0	0	188	16	2
29	0	0	188	16	3
30	0	0	188	16	2
31	0	3	188	16	3
32	0	5	188	16	2
33	3	6	188	16	2
34	3	6	188	16	2
35	0	2	188	16	2
36	0	1	188	16	3
37	0	0	188	16	3
38	0	0	188	16	3
39	0	0	188	16	2
40	0	0	188	16	3
41	0	0	188	16	2
42	0	0	188	16	3
43	0	0	188	16	2

44	0	0	188	16	3
45	0	0	188	16	2
46	0	0	188	16	3
47	0	0	188	16	2
48	6	0	188	17	2
49	6	0	188	16	3
50	6	0	188	16	2
51	0	0	188	16	2
52	0	0	188	16	2
53	0	0	188	16	2
54	0	0	188	16	2
55	0	0	188	16	3
56	0	0	188	16	3
57	0	0	188	16	2
58	0	0	188	16	2
59	0	0	188	16	2
60	0	0	188	16	2
61	1	0	188	16	2
62	0	0	188	16	3
63	0	0	188	16	3
64	0	0	188	16	2
65	0	0	188	16	3
66	0	0	188	16	2
67	0	0	188	16	2
68	0	0	188	16	3
69	0	0	188	16	2
70	0	1	188	16	2
71	2	2	188	16	3
72	0	2	188	16	2
73	0	0	188	16	2
74	0	0	188	16	3
75	0	0	188	16	3
76	0	0	188	16	2
77	0	0	188	16	3
78	0	0	188	16	3
79	0	2	188	16	3
80	1	0	188	16	2
81	0	0	188	16	3
82	0	0	188	16	2
83	0	0	188	16	2
84	0	0	188	16	2
85	0	0	188	16	2
86	0	0	188	16	2
87	0	0	188	16	3
88	0	0	188	16	3
89	0	0	188	16	2
90	0	0	188	16	3
91	0	0	188	16	3
92	0	0	188	16	2

93	0	0	188	16	2
94	0	0	188	16	3
95	0	0	188	16	3
96	0	0	188	16	2
97	0	0	188	16	2
	0	0			

LS= Left sensor (load cell), HS= Rein horizontal sensor (Encoder)

RS=Right sensor (load cell), VS = Rein vertical sensor (Encoder)

Appendix (G) Sample5

Seared control system test, samples (participant's)

Order	Rein LS	Rein RS	Motor S	Rein HS	Rein VS
0	0	0	20	14	3
1	0	0	20	15	3
2	0	3	20	14	3
3	0	2	20	14	3
4	0	0	20	14	3
5	1	0	20	14	4
6	1	0	20	14	3
7	0	0	20	14	4
8	0	0	19	15	4
9	0	2	19	14	4
10	0	2	19	14	4
11	0	0	19	14	4
12	0	0	19	14	4
13	0	0	19	14	4
14	0	0	18	14	4
15	0	0	18	15	1
16	0	0	18	15	1
17	0	0	18	15	1
18	0	0	18	15	1
19	0	0	18	15	2
20	0	0	2	31	3
21	0	4	17	15	3
22	3	6	17	15	4
23	3	6	17	14	4
24	0	6	17	14	4
25	0	0	17	12	4
26	0	0	16	12	4
27	0	0	17	12	4
28	0	0	16	12	4
29	0	0	16	12	4
30	0	0	16	12	4
31	0	0	16	12	2
32	0	0	16	14	1
33	0	0	16	14	4
34	0	0	15	14	4
35	6	1	15	14	2
36	6	1	15	15	4
37	6	1	15	15	4
38	0	1	15	14	2
39	0	0	15	15	4
40	0	0	17	14	4
41	0	0	17	12	4
42	0	0	16	12	4

43	0	0	17	12	4
44	0	0	16	12	4
45	0	0	16	12	4
46	0	0	16	12	4
47	0	0	16	12	2
48	0	0	16	14	1
49	0	0	16	14	4
50	0	0	15	14	4
51	0	0	15	14	2
52	0	0	15	15	4
53	0	0	15	15	4
54	0	0	15	14	2
55	0	0	17	14	4
56	0	0	17	12	4
57	0	0	16	12	4
58	0	0	17	12	4
59	0	0	16	12	4
60	0	0	16	12	4
61	0	0	16	12	4
62	0	0	16	12	2
63	0	0	16	14	1
64	0	0	16	14	4
65	0	0	15	14	4
66	0	0	15	14	2
67	0	0	15	15	4
68	0	0	17	14	4
69	0	0	17	12	4
70	0	0	16	12	4
71	0	3	17	12	4
72	0	2	16	12	4
73	0	0	16	12	4
74	1	0	16	12	4
75	1	0	16	12	2
76	0	0	16	14	1
77	0	0	16	14	4
78	0	2	15	14	4
79	0	2	15	14	2
80	0	0	15	15	4
81	0	0	15	15	4
82	0	0	15	14	2