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PRINT FIG. 1

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NASA/MSFC

GLOBAL POSITIONING SYSTEM SYNCHRONIZED ACTIVE LIGHT AUTONOMOUS DOCKING SYSTEM

This invention relates to a Global Positioning System Synchronized Active Light Autonomous Docking System (GPSSALADS) **11** for automatically docking a chase vehicle with a target vehicle. It comprises at least one active light emitting target **12** attached to the target vehicle. The target **12** includes an array of non-planar concomitantly flashing lights **21**, **22** and **23** which flash at a common frequency. A visual tracking sensor **13** is attached to the chase vehicle for detecting and tracking the target **12**. Its performance is synchronized with the flash frequency of the lights **21**, **22** and **23** by first and second internal clocks **18** and **27** connected to the target **12** and tracking sensor **13**, respectively. First and second Global Positioning System (GPS) receivers **19** and **28** are connected to the first and second internal clocks **18** and **27**, respectively, for providing simultaneous synchronization pulses to the internal clocks **18** and **27**, respectively. In addition, a docking process controller **14** is attached to the chase vehicle and is responsive to the visual tracking sensor **13** for producing commands for the guidance and propulsion system of the chase vehicle. The novelty of the invention is the use of the GPS receivers **19** and **28** to synchronize the active target **12** and the tracking sensor **13**.

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MFS-28853-1 PATENT APPLICATION

A GLOBAL POSITIONING SYSTEM SYNCHRONIZED ACTIVE LIGHT AUTONOMOUS DOCKING SYSTEM

ORIGIN OF THE INVENTION

The invention described herein was made by employees of the United States Government and may be manufactured and used by or for the Government for Government purposes without the payment of any royalties thereon or therefor.

FIELD OF THE INVENTION

The present invention relates to the docking of a mobile vehicle such as a spacecraft, aircraft, boats and land vehicles, and more particularly to an automatic docking system which obviates the need for external assistance or intervention. In even greater particularity, the present invention relates to a new and improved optoelectronic Global Positioning System Synchronized Active Light Autonomous Docking System (GPSSALADS) wherein a target vehicle utilizes an active light target which flashes intermittently and which is synchronized with a visual tracking sensor and image-processing circuitry operatively attached to an approaching chase vehicle by synchronization signals received from a standard Global Positioning System receiver.

BACKGROUND OF THE INVENTION

The development by the National Aeronautics and Space Administration (NASA) of Space Station Freedom has fostered a new impetus toward the development of a completely automated rendezvous and docking system. Many future missions into space will involve rendezvous and docking scenarios that are virtually impossible, risky or uneconomical if ground piloted control of the docking procedure is used because of the long time delays involved. Even operations taking place in Earth orbit are subject to time delays on the order of several seconds.

Initially, the rendezvous or docking of two spacecraft was primarily a manual operation. Such maneuvers were executed by highly trained astronauts, visually acquiring and tracking a target vehicle, while manipulating control mechanisms to fly the chase vehicle during the last roughly 1000 feet of the vehicle trajectory to a desired docking point. Although radar and inertial measurement data were often available to the astronaut so as to provide more accurate information about the spacecraft's position and attitude, the burden was on the astronaut to visually estimate the attitude of the target vehicle relative to his own chase vehicle. Some vehicles included three-axis (roll,

pitch and yaw) autopilots to assist in maintaining vehicle attitude. However, these autopilots are incapable of generating the control signals necessary for translation (x, y and z axis) maneuvers.

It will be appreciated by one skilled in the art that using a human astronaut for docking a space vehicle involves a number of disadvantages in addition to those discussed above. For example, there are inherent limitations on the accuracy of an astronaut's estimates with respect to geometrical relations (i.e., angles and distances). Likewise, humans lack the ability to exactly repeat the same control inputs. Therefore, such considerations must be factored into vehicle design as well as mission planning in order to ensure that the required margin of safety is provided resulting necessarily in increased costs and decreased operational flexibility.

To illustrate, docking mechanisms must be overdesigned in order to withstand impacts at high velocities that may occur with astronaut error. In addition, costly time-consuming "pilot-in-the-loop" simulations must be performed to verify the suitability of the information provided to the pilot in both normal and contingency situations.

In response to the inherent limitations and deficiencies of manual docking operations, unmanned docking systems were created. In a limited number of situations, these systems can be successfully accomplished by teleoperations or remote control. Such techniques rely on downlink telemetry of TV images which are monitored by ground control. Guidance commands are then transmitted back to the vehicle on the telemetry uplink. However, systems using communication uplinks usually require a wide bandwidth because both high rate telemetry and video displays are normally needed by ground control which, in turn, tend to be costly and invariably encounter interference problems. Furthermore, the end-to-end time delay introduced by the communications link will degrade the performance of the ground control in docking the chase vehicle, thereby increasing the chances of failure. Therefore, the large number of future docking missions and the vastness of space eliminate the use of teleoperations in many scenarios.

Similarly, although Radio Frequency (RF) technology has long been developed for acquiring and tracking targets for various purposes, the magnitude of RF wavelengths preclude operation at very close ranges and cannot be adapted for the precision measurement requirement required for automated

docking. Moreover, RF systems also tend to be plagued with interference problems.

In response to the above deficiencies, various attempts have been made to improve on the unmanned docking of two spacecraft. Interestingly, U.S. Pat. No. 5,109,345 discloses a non-synchronized passive docking system comprising a passive reflector target having three reflective areas thereon affixed to a target vehicle and a tracking sensor attached to a chase vehicle.

The system further comprises a laser diode array mounted on the chase vehicle for illuminating the reflective areas on the passive reflector target which causes light to be reflected therefrom. Substantial eye-safety problems are present if humans occupy the target vehicle. The tracking sensor detects the reflected light and produces electrical output signals in accordance with reflected images thereof.

As noted above with the teleoperated docking systems, this passive reflective docking system possesses many drawbacks. A major disadvantage of this system is that it requires a great expenditure of optical power for an adequate return of illumination from the target. This is particularly true for large targets when there is especially large distances between the chase vehicle and the target. Thus,

passive reflective docking systems must illuminate the target with high-powered lasers. When such a system is used with a manned target vehicle (such as Space Station Freedom), human safety is compromised in that the occupants will be at extreme risk of exposure to laser light.

Moreover, the passive reflector areas on the target are frequently subject to bombardment by micrometeorites. There is a very good probability of target damage to a point where their reflectiveness is inadequate. Unfortunately, this damage may not be discovered until a docking maneuver is attempted, which then may prove to be too late.

In addition, the passive reflective system must also expend a great amount of internal processing power to omit data received from a "non-reflecting" target (i.e., noise). In essence, since the system is non-synchronized, it must "subtract" all of the pictures of a "non-lit" target from a picture with the target lit per cycle in order to generate adequate docking commands, otherwise there would be an unacceptably small signal-to-noise ratio. Clearly, a non-synchronized system having a camera operating at 30Hz or more will require substantial internal processing power.

Preliminary work in this field relating to autonomous docking systems includes that described in Tietz, J.C. and

Kelly, J.H.: Development of an Autonomous Video Rendezvous and Docking System, Martin Marietta Corporation, Contract No. NAS8-34679, Phase One, (June 1982); Dabney, Richard W.: Automatic Rendezvous and Docking, A Parametric Study, NASA Technical Paper No. 2314, (May 1984); Tietz, J.C. and Richardson, T.E.: Development of an Autonomous Video Rendezvous and Docking System, Martin Marietta Corporation, Contract No. NAS8-34679, Phase Two, (June 1983); and Tietz, J.C.: Development of an Autonomous Video Rendezvous and Docking System, Martin Marietta Corporation, Contract No. NAS8-34679, (Jan. 1984).

While the above-mentioned systems are suited for their intended purpose, none of them disclose a Global Positioning System Synchronized Active Light Autonomous Docking System (GPSSALADS) wherein a target vehicle incorporates an active light target having active illuminators which flash intermittently and which are synchronized with a visual tracking sensor and image-processing circuitry on a chase vehicle by time signals received from a standard Global Positioning System receiver located on both the chase and target vehicles.

Inasmuch as the art is relatively crowded with respect to these various types of passive reflective docking

systems, it can be appreciated that there is a continuing need for and interest in improvements to such systems, and in this respect the present invention addresses this need and interest.

SUMMARY OF THE INVENTION

In view of the foregoing disadvantages inherent in the known types of docking systems now present in the art, the present invention provides a new and improved Global Positioning System Synchronized Active Light Autonomous Docking System (hereinafter referred to as "GPSSALADS"). As such, the principal object of the present invention, which will be described subsequently in greater detail, is to provide a new and improved GPSSALADS which has all of the advantages of the prior art and none of the disadvantages.

In support of the principal object, a further object of the present invention is to provide a new and improved GPSSALADS which enables any mobile vehicle to be docked without any outside assistance or intervention, thereby eliminating the need for either manned or teleoperated piloting of the mobile vehicle.

In further support of the principal object, another object of the present invention is to provide a new and improved GPSSALADS which makes it possible for a chase

vehicle to be automatically docked with a target vehicle by using active illuminators on the target vehicle which flash simultaneously and are synchronized with a visual tracking sensor and image-processing circuitry on the chase vehicle by use of Global Positioning System time signals (i.e., synchronization pulses).

Another object of the present invention is to provide a new and improved GPSSALADS which dispenses with the need for laser illumination of passive reflectors, such as corner cube reflectors or reflective tape, on the target vehicle.

Still another object of the present invention is to provide a new and improved GPSSALADS which obviates the need for a RF link between the chase and target vehicles, thus eliminating RF interference problems.

It is another object of the present invention to provide a new and improved GPSSALADS that generates more optical signal or signature for a given output power, when compared to passive reflective docking systems, thus reducing the total optical power required for autonomous docking.

It is a further object of the present invention to provide a new and improved GPSSALADS which has a very high signal to noise ratio due to the fact that the system is synchronized by Global Positioning System synchronization

pulses which are external time signals accurate to better than 100 microseconds, thus significantly reducing noise.

An even further object of the present invention is to provide a new and improved GPSSALADS which provides for a much larger visible angle of approach by the chase vehicle when compared to the passive reflective docking systems due to the more intense light or optical signal emanating from the active illuminators.

Even still another object of the present invention is to provide a new and improved GPSSALADS which will allow the chase vehicle to begin acquiring and tracking the target vehicle at approximately 1000 meters, which is farther than most passive reflective systems, based on the fact noted above that the target vehicle's active illuminators are much more intense than the reflected light off of passive retroreflectors.

Yet another object of the present invention is to provide a new and improved GPSSALADS that can be used at potentially any place by any mobile vehicle where autonomous rendezvous and docking will be used including but not limited to Space Station Freedom.

Even still a further object of the present invention is to provide a new and improved GPSSALADS which can be tested

for proper functioning prior to any attempted autodocking sequence, thus eliminating a problem plaguing passive reflector systems wherein the reflectors are hit by micrometeorites and damaged to where they no longer reflect, the damage not being discovered until a docking maneuver is attempted.

Another object of the present invention is to provide a new and improved GPSSALADS which will provide for a very soft dock between the chase and target vehicles.

An even further object of the present invention is to provide a new and improved GPSSALADS which will use a series different sized active light targets that flash at different times for preventing lights from one target merging with lights of another target and for improving long range accuracy and for accommodating different fields of view of the chase vehicle.

Yet a further object of the present invention is to provide a new and improved GPSSALADS which will not utilize lasers thus obviating the problems of eye safety when the target vehicle is occupied by humans.

It is a further object of the present invention to provide a new and improved GPSSALADS that utilizes xenon

strobe lights and light emitting diodes for its active illuminators.

Even still another object of the present invention is to provide a new and improved GPSSALADS which will utilize the geometry of the target vehicle for its active light target.

These together with other objects of the present invention, along with the various features of novelty which characterize the invention, are accomplished through the use of Global Positioning System Synchronized Active Light Autonomous Docking System (GPSSALADS). The primary purpose of the system is to automatically dock a chase vehicle with target vehicle. It comprises at least one active light emitting target which is operatively attached to the target vehicle. In a preferred embodiment, the active light target consists of a base plane, a central post extending outwardly from the base plane, a pair of flashing lights or illuminators, which may be xenon strobe lights or light emitting diodes, located on the base plane on opposite sides of the central post, and a third flashing light located at the free end of the central post. The flashing lights concomitantly flash at a controlled common frequency.

The GPSSALADS further comprises a visual tracking sensor operatively attached to the chase vehicle. Generally, the

cooperative performance of the visual tracking sensor with the active light target defines a synchronized active light target subsystem. The visual tracking sensor includes a video imaging device, which can be a solid state video camera, and is operatively coupled to an image processing unit. In operation, the concerted action of these two components detect the flashing lights and generate electrical signals corresponding to the computed centroids of the light images. Moreover, the performance of both components are synchronized with the flash frequency of the lights by a synchronization means which will be discussed in greater detail below.

The GPSSALADS further comprises a software processor or signal processing means for processing the electrical signals generated by the image processing unit. It produces its own output signals corresponding to the relative range, roll, pitch, yaw, azimuth and elevation between the chase and target vehicles. This signal processing means may be an inverse perspective processor which performs an inverse perspective algorithm to derive the relative position and attitude between the vehicles.

In addition, the GPSSALADS includes a docking process controller means which is operatively attached to the chase

vehicle. It is responsive to the relative position and attitude output signals generated by the signal processing means, and based thereon, produces commands for the guidance and propulsion system of the chase vehicle.

As referred to above, the synchronization means is comprised of a first internal clock operatively connected to the active light target and a second internal clock operatively connected to the visual tracking sensor. The purpose of both clocks is to provide timing control signals to the active light target and the visual tracking sensor, respectively.

The synchronization means further includes a first Global Positioning System receiver operatively connected to the first internal clock and a second Global Positioning System receiver operatively connected to the second internal clock. The receivers continually or repeatedly provide simultaneous synchronization pulses to the internal clocks, respectively, for keeping the clocks accurate and updated.

Since the distance between two vehicles is always changing during the docking thereof, the GPSSALADS may employ a series of active light targets for accommodating and adapting to the different ranges between the vehicles. The targets can be scaled sizes in comparison to one another and

their lights will flash at different times (i.e., independently from one another) for eliminating any light merging problems.

There has thus been outlined, rather broadly, the more important features of the invention in order that the detailed description thereof that follows may be better understood, and in order that the present contribution to the art may be better appreciated. There are, of course, numerous other novel features of the present invention that will become apparent from a study of the drawings and the description of the preferred embodiment and which will form the subject matter of the claims appended hereto.

Moreover, it is to be understood that the phraseology and terminology employed herein are for the purpose of description and should not be regarded as limiting. As such, those skilled in the art will appreciate that the conception, upon which this disclosure is based, may readily be utilized as a basis for the designing of other systems for carrying out the several purposes of the present invention. It is important, therefore, that the claims be regarded as including such equivalent systems insofar as they do not depart from the spirit and scope of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing objects and advantages of the present invention for a new and improved Global Positioning System Synchronized Active Light Autonomous Docking System (GPSSALADS) will be more readily understood by one skilled in the art by referring to the following detailed description of a preferred embodiment and to the accompanying drawings which form a part of this disclosure, and wherein:

FIG. 1 is a schematic representation, partially in block diagram form, of a preferred embodiment of the Global Positioning System Synchronized Active Light Autonomous Docking System;

FIG. 2 is a front elevational view of an optical docking aid having active illuminators;

FIG. 3 is a schematic representation, partially in block diagram form, of an alternative embodiment of the Global Positioning System Synchronized Active Light Autonomous Docking System; and

FIG. 4 is a flow chart of the overall autodocking sequence using the GPSSALADS of FIG. 1.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to the drawings for a clearer understanding of the present invention, FIG. 1 discloses a Global Positioning

System Synchronized Active Light Autonomous Docking System (hereinafter referred to as "GPSSALADS") **11** which contemplates the use of an active light target **12**, a visual tracking sensor **13**, a docking process controller **14** and thruster hardware **16**. The overall purpose of the GPSSALADS **11** is to orchestrate the automatic soft docking of a chase vehicle (not shown) with a target vehicle (not shown) from a range starting at approximately 1000 meters.

The active light target **12**, shown in dashed lines in FIG. 1, is operatively attached to the target vehicle whereas the visual tracking sensor **13**, also shown in dashed lines in FIG. 1, is operatively attached to the chase vehicle. The concerted performances of the active light target **12** and the visual tracking sensor **13** comprise a novel synchronized active light autonomous target subsystem which is one of the keystone features in the present invention for facilitating the automatic soft docking of the chase vehicle with the target vehicle.

As illustrated in FIGS. 1 and 2, the active light target **12** is comprised of an optical docking aid **17**, a docking aid internal clock **18**, and a docking aid Global Positioning System (GPS) receiver **19**. The optical docking aid **17** includes a light emission or illumination means for emitting

light therefrom which is comprised of a plurality of lights or active illuminators **21, 22** and **23** in spaced relation to one another. In a preferred embodiment, the active illuminators **21, 22** and **23** may be either xenon strobe lights or light emitting diodes, depending on the size of the target **12** and range between the chase and target vehicles. Most importantly, the active illuminators **21, 22** and **23** concomitantly flash at a controlled common frequency which is approximately one hertz (1Hz), but may be higher or lower if the situation warrants.

The visual tracking sensor **13** includes a video imaging device **24**, which can be any known type of video camera in the art but preferably a thirty hertz (30Hz) solid state video camera. It is operatively coupled or linked to an image processing unit **26** (i.e., computer). In operation, the cooperative actions of the video imaging device **24** and the image processing unit **26** detect and track the flashing active illuminators **21, 22** and **23**. This involves the acquisition of frames of video by the video imaging device **24** and the generation of electrical signals by the image processing unit **26** corresponding to the computed centroids of the light images obtained in the frames of video.

The coordinated performances of the video imaging device **24** and the image processing unit **26** are synchronized, thus acting in unison, with the flash frequency of the active illuminators **21, 22** and **23** by a synchronization means operatively and separately attached to both the active light target **12** and the visual tracking sensor **13,** respectively.

The synchronization means is comprised of the docking aid internal clock **18** which is operatively connected to the optical docking aid **17** and a tracking sensor internal clock **27** operatively connected to both the image processing unit **26** and the video imaging device **24,** respectively. Both clocks **18** and **27** not only maintain a base time reference but act as timing controllers by providing timing control signals to the optical docking aid **17,** image processing unit **26** and video imaging device **24,** respectively.

Specifically, the docking aid internal clock **18** controls the frequency at which the active illuminators **21, 22** and **23** flash which, as noted above, is preferably one hertz (1Hz). The tracking sensor internal clock **27,** on the other hand, controls the frequency at which both the video imaging device **24** and the image processing unit **26** operate. In a preferred embodiment, the video imaging device **24** acquires frames of video at a frequency of thirty hertz (30Hz). The image

processing unit **26** operates at two hertz (2Hz) and, therefore, both receives and processes one acquired frame of video at least twice per second. Since the active illuminators **21, 22** and **23**, video imaging device **24** and image processing unit 26 are synchronized, one of the frames of video acquired by the image processing unit **26** will be of an "illuminated" docking aid **17** while the other is of a "non-illuminated" docking aid **17**.

The general requirement is that when the image processing unit **26** is not receiving a frame of video from the video imaging device **24**, it is processing the frame it did receive in order to generate the above mentioned electrical signals corresponding to the centroids of the light images. For reasons discussed later, the internal clock **27** can, if necessary, be used to control one or more active light targets **12**. That is, the GPSSALADS **11** will accommodate and adapt to the concurrent use of a plurality or series of active light targets **12**.

Moreover, the GPSSALADS **11** is designed to use significantly less internal processing power when compared to passive or non-synchronized systems. As noted above, every other frame of video received by the image processing unit **26** will be of an "illuminated" docking aid **17**, while the other

is of a "non-illuminated" docking aid **17**. Even though the video imaging device **24** provides thirty (30) frames of video per second to the image processing unit **26**, the image processing unit **26**, being synchronized with the video imaging device **24** and optical docking aid **17**, utilizes (i.e., receives and processes) only two (2) of the thirty (30) frames per second, thus substantially reducing its internal processing power requirement. In direct contrast, non-synchronized systems must process substantially more (i.e., usually all) of the frames of video acquired by the video camera, as opposed to only two frames, to assure that an "illuminated" target is obtained, thus requires significantly more internal processing power than the GPSSALADS **11**.

The synchronization means is further comprised of the docking aid Global Positioning System (GPS) receiver **19** operatively connected to the docking aid internal clock **18** and a tracking sensor Global Positioning System (GPS) receiver **28** operatively connected to the tracking sensor internal clock **27**. The GPS receivers **19** and **28** continuously provide simultaneous synchronization pulses to the internal clocks **18** and **27**, respectively, for updating the clocks and maintaining their accuracy. The frequency of the

synchronization pulses is preferably one hertz (1Hz) but may be higher or lower depending on the docking scenario. Moreover, the pulses are accurate to better than 100 microseconds, which is much greater than is required for the present invention.

The optical docking aid **17** may assume a variety of structural configurations. As shown in FIGS. 1 and 2, a preferred embodiment of the optical docking aid **17** is comprised of a base plane **29**; a central post **31** extending outwardly from the base plane **29**; a pair of first and second active illuminators **21** and **22** attached to the base plane **29** on opposite sides of the central post **31**; and a third active illuminator **23** affixed at the free end of the central post **31**. The primary purpose of the above optical docking aid **17** configuration is to provide a three-dimensional or non-planar array of active illuminators **21, 22** and **23**. As will be discussed below in greater detail, such three-dimensional array is instrumental in allowing the visual tracking sensor **13** to use an inverse perspective algorithm for deriving the relative position and attitude needed for docking. Furthermore, this configuration gives maximum sensitivity for yaw and pitch at zero degrees.

The three active illuminators **21, 22** and **23** are the minimum required for a six-degree-of-freedom relative state determination (i.e., to facilitate derivation of all six error signals that are provided in accordance with the present invention, although a fourth active illuminator, not shown, could be added to provide complete knowledge of the relative vertical orientation, right-side-up versus upside-down). However, this same purpose is served by making active illuminator **22** larger in the illustrated preferred embodiment.

Moreover, the third active illuminator **23** and the central post **33** may be omitted. The only effect will be that the relative pitch and yaw would not be derived.

The range between the chase vehicle and target vehicle along with the angle of approach of the chase vehicle, are factors which influence the size of the optical docking aid **17** and the types active illuminators **21, 22** and **23.** Since the autodocking sequence normally begins when the range between the vehicles is at least 1000 meters, a series or plurality of active light targets **12,** preferably three (large, medium and small), may be utilized to accommodate the Field of View (FOV) capability of the video imaging device **24**

which is known in the art. All three active light targets **12** are operatively attached to the target vehicle.

For a large active light target **12**, the distance between the first and second active illuminators **21** and **22**, located on the base plane **29**, is approximately four meters. The center pole height is approximately twenty centimeters.

For a medium active light target **12**, the distance between the first and second active illuminators **21** and **22** is approximately ninety centimeters while the center pole height is approximately twenty centimeters. The distance between the first and second active illuminators **21** and **22** on a small active light target **12** is approximately eight centimeters having a pole height of five centimeters.

When the present invention is utilizing three active light targets **12**, the visual tracking sensor **13** begins to acquire and track the large active light target **12** outside 1000 meters. At a close enough range which is determined by the FOV capability of the video imaging device **24**, the visual tracking sensor **13** acquires the medium active light target **12**. The sensor **13** then tracks both the large and medium active light targets **12** as the chase vehicle closes on the target vehicle. As the range decreases, the large target **12** image becomes too large for the FOV of the video imaging

device **24** and becomes unusable. The visual tracking sensor **13** then tracks the medium target **12** while the chase vehicle moves closer to the target vehicle. At a close enough range, the visual tracking sensor **13** acquires the small active light target **12**. It then tracks both the medium and small targets **12**. Finally, the medium target **12** image becomes too large and is unusable, leaving the small target **12** to guide the chase vehicle to a soft dock. There should be no gaps where one target **12** image becomes too large to be unusable while the next smaller target **12** image is still too small to be tracked by the visual tracking sensor **13**. This requirement is accommodated by using the different sized targets **12** as defined above, however, the GPSSALADS **11** may utilize more than three targets **12**.

Moreover, the series of active light targets **12** should flash at different times or out of phase so that illuminators from one target **12** never merge with illuminators of another target **12** in a frame of video acquired by the video imaging device **24**. Thus, in a preferred embodiment, the frames of video acquired will alternate between the two targets **12**, which are then separately processed by the image processing unit **26**.

Referring again to FIG. 1, the visual tracking sensor **13** may further comprise a signal processing means for processing the electrical signals generated by the image processing unit **26**. It is comprised of a software processor **32** which is operatively linked to the image processing unit **26**. In operation, the processor **32** produces its own output signals **33** corresponding to the relative range, roll, pitch, yaw, azimuth and elevation between both the chase and target vehicles. In a preferred embodiment, the software processor **32** may be an inverse-perspective processor which performs a inverse perspective algorithm, which is known in the art, to compute the relative position and attitude of the vehicles.

The output signals **33** corresponding to the relative position and attitude are then supplied to an autonomous docking process controller means **34** for producing angular and translation motion commands for the steering and propulsion system of the chase vehicle. In a preferred embodiment, the docking process controller means **34** is a closed-loop position feed-back control arrangement having six input control channels corresponding to the relative position and attitude set out above, and is operatively attached to the software processor **32** on the chase vehicle.

In an alternative embodiment, as illustrated in FIG. 3, the active light target **12** may be operatively attached to the chase vehicle whereas the visual tracking sensor **13** is operatively attached to the target vehicle. The output signals **33** generated by the software processor **32** corresponding to the relative position and attitude between the vehicles occurs on the target vehicle, therefore must be transmitted or communicated to the docking process controller means **34**, or more specifically to the docking process controller **14** via a communication link **35**, which is located on the chase vehicle, by RF signals or optical signals.

In all embodiments, the docking process controller means **34** is comprised of the docking process controller **14** and thruster hardware **16**. The docking process controller **14** provides a sequence of operations to generate motion or thruster commands **36** for the chase vehicle's propulsion system or thruster hardware **16**. It should be noted, however, that the docking process controller **14** and thruster hardware **16** may assume a variety of configurations which are well known in the art and are not germane to the present invention so long as they are responsive to the software processor **32** and capable of producing commands for the guidance and propulsion system of the chase vehicle. In this regard,

while the controller **14** described above is the simplest known that is capable of performing the task assigned, it is to be considered representative of more sophisticated embodiments. Therefore, further discussion of the controller **14** is omitted in the interest of clarity.

Referring to FIG. 4, a flow diagram is illustrated showing the basic steps for automatically docking the chase vehicle with the target vehicle having one active light target **12**. This flow diagram may be modified slightly to accommodate the simultaneous tracking of a series of active light targets **12**, as referred to above, and the embodiment shown in FIG. 3.

Terminal block **37** represents the beginning of the autodocking sequence, which initially involves the activation of the target vehicle's active light target **12**, as represented by processing block **38**. Activation may occur through the use of an on-board timer, a radio signal, an optical signal, or an on-board astronaut. Once it occurs, however, the active illuminators **21**, **22** and **23**, which are attached to the optical docking aid **17** on the active light target **12**, begin concomitant flashing at a frequency determined by the timing control signals received from the docking aid internal clock **18**. The internal clock **18** is

updated approximately once per second by the synchronization pulses received from the docking aid Global Positioning System receiver **19** to prevent substantially all drifting of the internal clock **18**.

Next, the chase vehicle's visual tracking sensor **13** begins acquisition of the active light target **12**, as represented by processing block **39**. The tracking sensor **13** becomes active in response to the timing control signals received from tracking sensor internal clock **27**. As with the docking aid internal clock **18**, the tracking sensor internal clock **27** is updated approximately once per second by the synchronization pulses received from the tracking sensor Global Positioning System receiver **28**, which are ubiquitous or simultaneous as those from the GPS receiver **19**. As with the active light target **12**, such synchronization or updating prevents substantially all drifting of the internal clock **27**.

In addition, acquisition of the active light target **12** by the visual tracking sensor **13** involves a determination by the image processing unit **26** as to whether one of the two frames of video acquired by the video imaging device **24** include three "light images" corresponding to the flashing active illuminators **21**, **22** and **23**, as represented by decision diamond **41**. As indicated by decision diamond **41**, if a

determination is made that the "light images" corresponding to the active illuminators **21, 22** and **23** are not present in a frame of video, the acquisition operation continues until they are present. When present, the processing operations by the image processing unit **26** are initiated including full tracking of the active light target **12,** as represented by processing block **42.** The processing of the "light images" comprises computing the centroids of the active illuminators **21, 22** and **23**, and producing electrical signals corresponding thereto.

The next step in the autodocking sequence is the performance of calculations by the software processor **32,** as indicated by processing block **43.** The software processor **32** processes the electrical signals generated by the image processing unit **26** and produces its own output signals corresponding to the relative ranges roll, pitch, yaw, azimuth and elevation between both vehicles. This is accomplished by an inverse-perspective projection technique. An explanation and basic equations needed for these calculations are set forth in the Teitz and Kelly reference referred to above.

Next, based on the six output signals generated by the software processor **32,** the docking process controller **14**

produces commands for the guidance and propulsion system of the chase vehicle, as represented by processing block **44**. The actual docking procedure is then executed which involves the firing of the thruster hardware **16** based on the chase vehicle commands derived from the guidance and propulsion algorithms.

In this regard, as indicated by decision diamond **46**, the docking procedure is terminated at this point if the vehicle commands do not provide for firing of the thruster hardware **16**, as represented by processing block **47**, if there has been a successful dock. In other words, if the vehicle is determined to be docked, the procedure is terminated, as represented by terminal block **48**. On the other hand, if the docking has not been completed, the thruster hardware **16** are fired and the basic procedure beginning with tracking of the optical docking aid **17** is repeated, as illustrated.

While the present invention is shown in one form, it would be obvious to those skilled in the art that it is not so limited but is susceptible of various changes and modifications without departing from the spirit thereof.

ABSTRACT OF THE DISCLOSURE

A Global Positioning System Synchronized Active Light Autonomous Docking System (GPSSALADS) for automatically docking a chase vehicle with a target vehicle comprising at least one active light emitting target which is operatively attached to the target vehicle. The target includes a three-dimensional array of concomitantly flashing lights which flash at a controlled common frequency. The GPSSALADS further comprises a visual tracking sensor operatively attached to the chase vehicle for detecting and tracking the target vehicle. Its performance is synchronized with the flash frequency of the lights by a synchronization means which is comprised of first and second internal clocks operatively connected to the active light target and visual tracking sensor, respectively, for providing timing control signals thereto, respectively. The synchronization means further includes first and second Global Positioning System receivers operatively connected to the first and second internal clocks, respectively, for repeatedly providing simultaneous synchronization pulses to the internal clocks, respectively. In addition, the GPSSALADS includes a docking process controller means which is operatively attached to the

chase vehicle and is responsive to the visual tracking sensor for producing commands for the guidance and propulsion system of the chase vehicle.

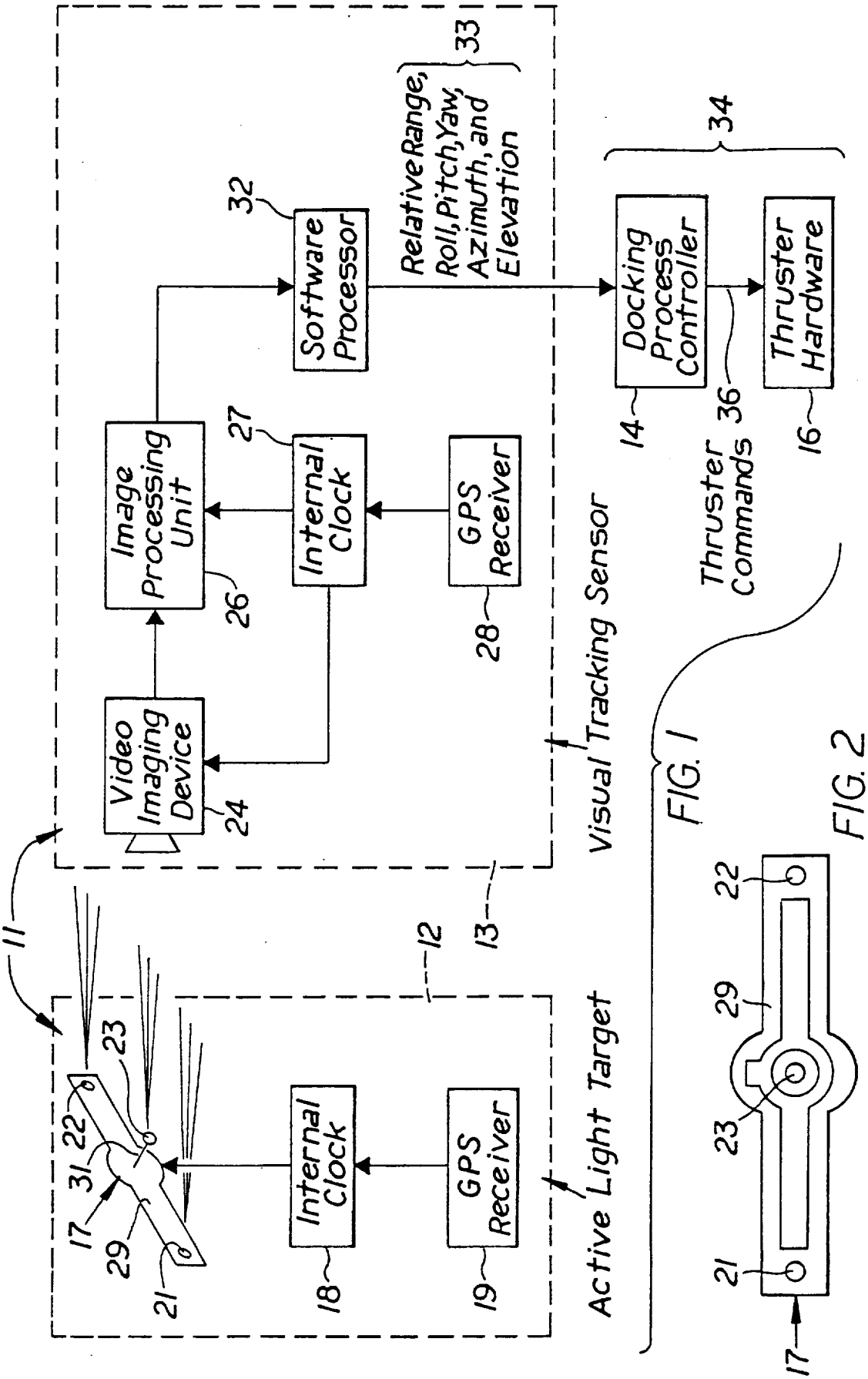

Video Imaging Device
24
Image Processing Unit
26
Internal Clock
27
GPS Receiver
28
Software Processor
32
Relative Range, Roll, Pitch, Yaw, Azimuth, and Elevation
33
Docking Process Controller
14
Thruster Commands
36
Thruster Hardware
16
34
Visual Tracking Sensor
13
11
12
Active Light Target
Internal Clock
18
GPS Receiver
19
17
29
21
31
22
23

FIG. 1

22
29
23
21
17

FIG. 2

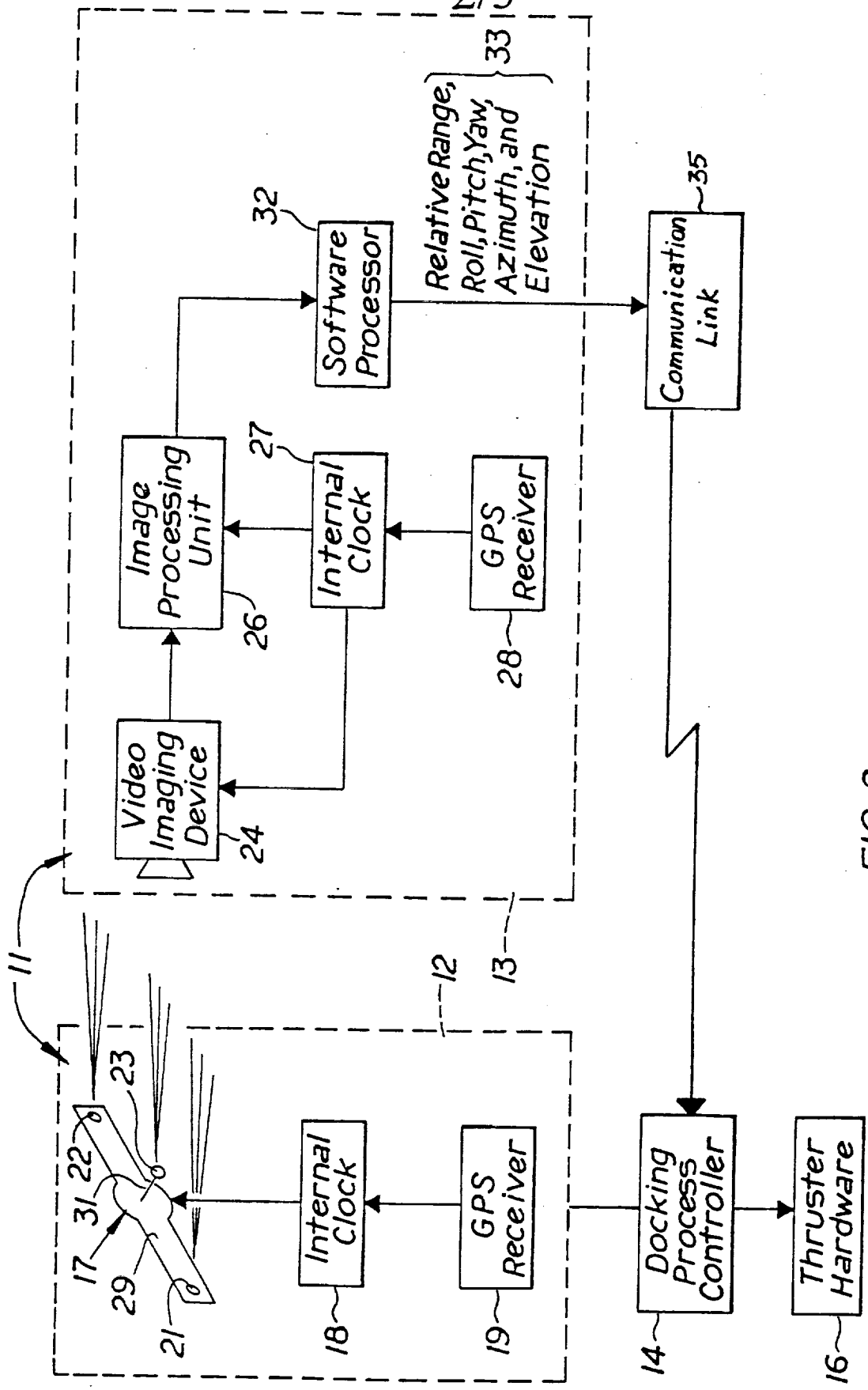
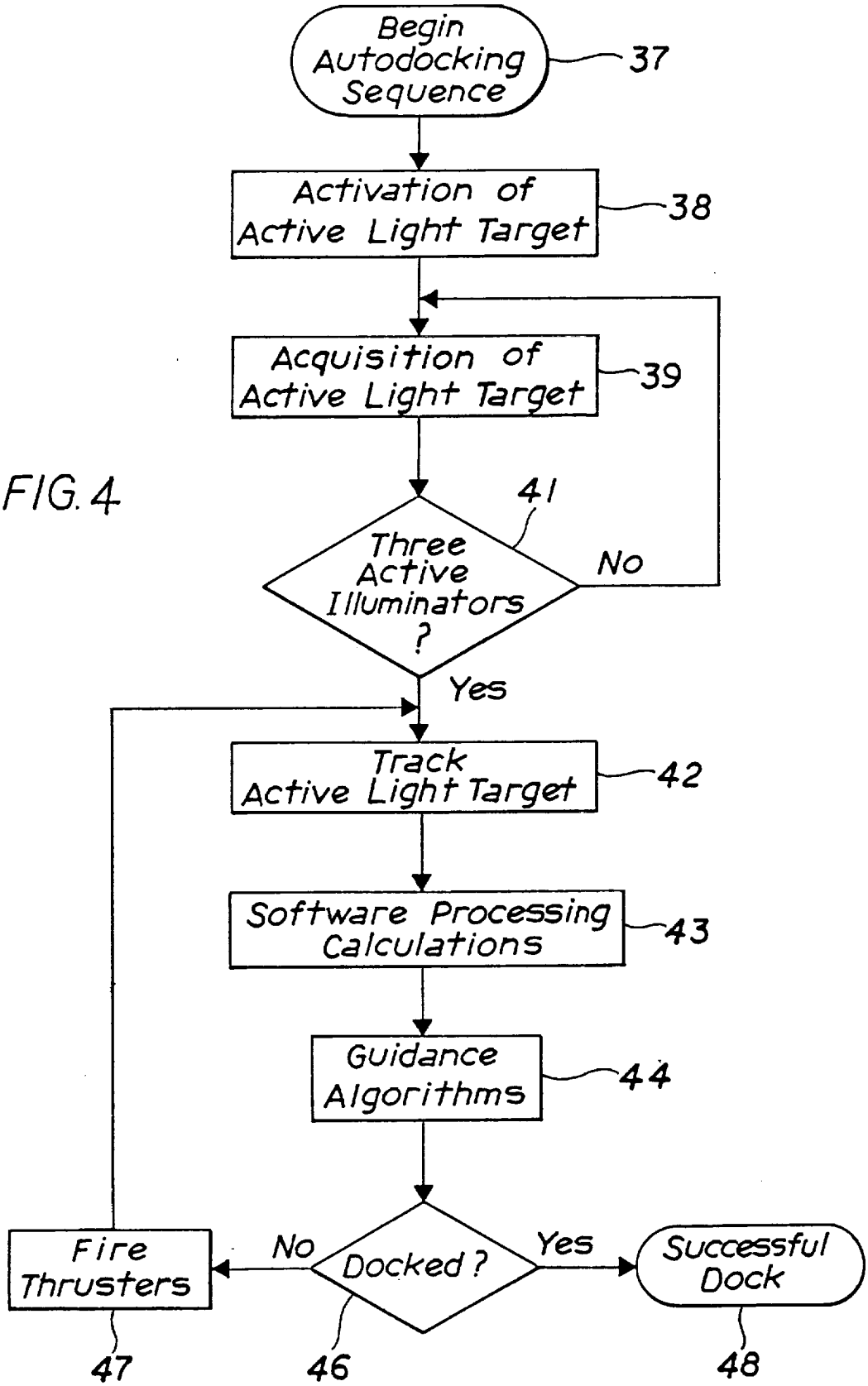

Relative Range, Roll, Pitch, Yaw, Azimuth, and Elevation
33
32
Software Processor
35
Communication Link
Image Processing Unit
27
Internal Clock
GPS Receiver
26
28
Video Imaging Device
24
11
12
13
23
22
31
17
29
21
Internal Clock
GPS Receiver
18
19
Docking Process Controller
Thruster Hardware
14
16

FIG. 3

FIG. 4


Begin Autodocking Sequence
37
Activation of Active Light Target
38
Acquisition of Active Light Target
39
Three Active Illuminators ?
41
No
Yes
Track Active Light Target
42
Software Processing Calculations
43
Guidance Algorithms
44
Docked ?
No
Yes
Fire Thrusters
47
46
Successful Dock
48